WATER-BORNE AND SOLVENT-BASED FLEXOGRAPHIC INKS—INFLUENCE ON UNCOVERED AREA AND INK LEVELING ON PE-COATED PAPERBOARD

Behudin Mesic, *Samrt Print, BrobyGrafiska Education 37. SE-686 80 Sunne, Sweden*

Gunnar Engström and Magnus Lestelius, *Karlstad University, Dept. of Chemical Engineering, Faculty of Technology and Science, SE-651 88 Karlstad, Sweden.*

ABSTRACT

A smooth and a rough PE-extrusion-coated paperboard, with and without corona treatment, were printed flexographically using a solvent-based and a water-borne ink with the objective to examine the influence of surface roughness and wetting of the paperboard on ink transfer, uncovered area (UCA), ink-film thickness distribution, ink leveling, and print unevenness. The results showed that ink transfer was significantly lower for the solvent-based ink, but because this ink has a stronger pigment, less ink was needed for a given ink density. Both inks were equally prone to yield UCAs, and both inks also formed dry ink layers with the same thickness distribution in the 2–4 mm range. Both inks also leveled out to same extent. The leveling was controlled by the corona treatment and reduced the UCAs. The smooth substrate exhibited the least UCAs. On a submillimeter level the print unevenness for the water-borne ink exhibited patterns that resemble crawling worms or curled thread ends aligned in the direction of the printing. The pattern for the solvent-based ink was grainy and without orientation. These patterns are suggested to reflect the splitting pattern of the ink during the transfer to the paperboard.

Keywords:

Printability, solvent-based ink, water-borne ink, surface roughness, PE-extrusion-coated paperboard, ink transfer, uncovered area, ink leveling, print unevenness

INTRODUCTION

Flexography is a progressive and widely applicable printing method for a wide range of substrates and finished products, such as foil, plastic film, corrugated board, paper, paperboard, or even fabric (Castelli, 1998; Zhang and Aspler, 1995). It is a printing method that has greatly expanded and is often preferred for package printing (Chalmers, 1997; Dowdell, 2001). Flexography generally uses low-viscosity inks, either solvent-based or water-borne, which dry very quickly between the printing units in the printing press (Cusdin, 1999). Solvent-based inks are formulated to contain a blend of alcohol that dissolves the resin and produces a liquid ink, while water-borne inks are generally dispersions, using water and amines for the liquefaction (Crouch, 1998).

Both solvent-based and water-borne inks solidify by loss of solvent/water (drainage and evaporation). Solvent-based inks give good adhesion, gloss, and flexibility on polymer-coated substrates and aluminum foil, and they provide good resistance to water, acid, and alkali (Nelson, 1993). Some disadvantages with using solvent-based inks are that they require venting, because odor is given off, and that environmental hazards increase, because the inks contain highly inflammable solvents. Water-borne inks share many common features with solvent-based inks and are said to be cost effective, when material and compliance costs are factored in (Nelson, 1993). Water-borne inks have advantages compared to solvent-based inks: they wash up with water, they do not swell most flexographic plates, they do not produce vapors hazardous to health, they reduce fire hazards and insurances costs, and their cost is less affected by fluctuations in the price of crude oil. However, water-borne inks also have disadvantages: they require more energy for drying, and they do not properly wet printing substrates with low surface energy, such as polymeric films (for example, polyethylene (PE) film and PE-coated board). Another disadvantage with water-borne inks is the handling of the waste and recycling of packaging material (Nelson, 1993; Maust, 1993).

A common and serious problem in flexographic printing, as well as with solvent-based and water-borne inks, is uncovered area (UCAs). The UCAs consists of a number of small dots, typically 0.04-0.9 mm^2 in size, that are supposed to be covered with ink but are not. When printing with water-borne inks, both local areas of low surface energy and depressions (Zang & Aspler, 1995, Barros et al. 2005) in the surface of the printing substrate have been reported to be able to cause UCAs. Experience within the printing industry is that solvent-based inks cause less UCAs than water-borne inks. Because solvent-based inks have significantly lower surface tension than water-borne inks, this suggests that solvent-based inks wet the printing substrate better and also level out better. Therefore, solvent-based inks are believed to be forgiving for areas of low surface energy of the printing substrate.

This paper is focused on UCAs and the issues of how much of the UCAs stem from local areas with low surface energy and how much stems from depressions in the surface of the printing substrate. To shed light on this issue, we performed a printing trial in which we printed a smooth and a rough PE-extrusion-coated paperboard, with (44 mJ/m^2) and without (<32 mJ/m^2) corona treatment, with a solvent-based ink and a water-borne ink respectively. Besides UCAs, the prints were tested with respect to ink transfer, dry ink-film thickness distribution, ink leveling, and print unevenness. The printing was performed at two line pressures.

MATERIALS AND METHODS

Inks

Two different inks supplied by Sun Chemical were used: 1) a water-borne ink (Cyan C SCANFULLTITE RASTER 713-45686 B 60750), and 2) a solvent-based ink (Cyan 473-QUATTROFLEX B 61659). The viscosity of both inks was adjusted to 29.5 s, according to a Zhan 2 cup. After the viscosity was adjusted, the surface tension, dry solids content, and density of the inks were 24.7 mJ/m^2, 22% and 0.93 g/mL for the solvent-based ink and 35.8 mJ/m^2, 32% and 1.0 g/mL for the water-borne ink. Surface tension was measured using the FIBRO DAT 500/1100 Dynamic Contact Angle and Absorption Tester.

Printing Substrates

A smooth pigment-coated (273 g/m^2) and a rough uncoated (252 g/m^2) liquid packaging paperboard—supplied by Stora Enso, Skoghall, Sweden—were PE-extrusion coated on a pilot scale by Tetra Pak, Lund, Sweden. The grammage of the PE layer was 12 g/m^2 for both paperboards. After the PE-extrusion coating, the liquid packaging boards were cut into 5.5 cm × 70.0 cm sheets, and half of the sheets were corona treated using Corona-Plus lab treater equipment (Vetaphone, Kolding, Denmark), designed for the corona treatment of polymer films or paperboard sheets. The corona power output was 2.0 kW using ceramic electrodes and an aluminum roll with a perimeter speed of 1.65 m/s. All sheets were stored at a constant temperature (23.5°C) and protected from light, air, moisture, and dust in sealed, partially transparent PE bags (protected sheets were first stored in small sheaves, each wrapped in PE-coated wrapping paper, and then stored in sealed, partially transparent PE bags). The untreated (0 kW) paperboard displayed a surface tension less than 32 dynes/cm and treated (2.0 kW) 44 dynes/cm, as measured by Vetaphone's PRO-DYN test pens (Vetaphone, Denmark).

The surface roughness of the PE-extrusion-coated sheets was measured using a profilometer (Perthometer C5D, Perthen, Germany) equipped with a narrow diamond needle with a radius of radius 2 m (Wågberg and Johansson, 1993). The R_a value for the smooth pigment-coated paperboard was 0.68 µm and for the rough paperboard 1.29 µm.

Experimental Design

The design of the printing experiments was performed using MODDE 5.0 software (Umetrics AB, Umeå, Sweden). With the intention to reduce the number of experimental points, the experiments were chosen according to a central composite face-centered (CCF) design. Four variables—nip-line load, surface energy level, type of ink, and printing substrate—were included, which resulted in 22 experimental points.

Printing

All printing was performed using an IGT F1 equipped for flexographic printing (IGT Testing Systems, Amsterdam, Netherlands). Three different printing plates (DuPont ACE, produced by FlexoPartner AB, Sunne, Sweden, using straight light illumination) with 100%, 70% and

30% tone values were used. The screen ruling of the printing plate was 24 lines/cm, the thickness was 1.70 mm, and its hardness was 71° shore A. The anilox roller had a screen ruling of 180 lines/cm, with an ink volume of 2.7 g/m^2, and a nip-line load of 125 N. The conditions during the printing were kept constant (50% RH and 23.5°C). Two levels of the line load between the printing plate and impression cylinder were used, 50 N and 150 N respectively. The printing speed was 0.4 m/s. For each experiment, three strips of 4 cm × 40 cm (long side in the CD direction) were printed.

The amount of copper originating from the ink pigment on a selection of a sheet from the printed material, as well as on the inks themselves, was measured using SCAN-CM 54:97 and SCAN-38:96 with exception of a liquefaction/decomposition time of 3 h (adapted to measure Cu) instead of 16 h (adapted to measure Cd).

Print Density, Print Unevenness, and UCAs

Print density was measured with an optical densitometer (Gretag Macbeth D19/47B/P, Regensdorf, Switzerland) connected to a computer for data acquisition. Print density is given as the mean value of 10 measurements on each strip.

Print unevenness and percentage of UCAs in fulltone print were measured with the help of image analysis using a flatbed scanner (Canon CanoScan D1250 U2F), with a resolution of 600 dpi for the imaging and software (STFI mottling v 2.6 software, developed by STFI, Stockholm, Sweden) for the image processing. The processing consists of a frequency analysis based on a fast Fourier transform (FFT). The result of print unevenness measurement is reported as the standard deviation or the coefficient of variation within these wavelength bands (expressed in mm): 0.125–0.25, 0.25–0.50, 0.50–1.0, 1.0–2.0, 2.0–4.0, and 4.0–8.0. The result of UCA measurement is reported as a percentage of uncovered areas. The sample size was 21.7 mm × 21.7 mm. We report the mean value of the measurements of six such areas.

Visual Assessment of UCAs

The visual assessment (rating) of the amount of UCAs was made by eight observers (four male and four female). The observers were asked to estimate the degree of UCAs in fulltone print. The rating of UCAs required the observers to give a numerical assessment of what degree of total printed area they considered to not be covered by ink. A scale of 1 to 8 (1 for the lowest degree of UCAs and 8 for the highest) was used for the rating. The result is expressed as the average value of eight statements. The size of the printed samples used for visual assessment was 40 mm × 90 mm. Due to the large number of printed samples, the assessment was restricted to the material printed at the lower printing pressure (50 N).

Light Microscopy

For microscopic evaluation of the print, a microscope of the brand Leica MZ 12 (Meyer Instruments, Houston, U.S.A.) was used for the examination in side light. Side lighting was provided by the Leica CLS 150X (150W cold light source with optical fiber light guides and ringlights), with a light incident angle of 30° and a 10 cm distance from the investigated sample. The microscope was equipped with 2.5 x1 magnifications and a Nikon DXM 1200 digital camera for capturing images (3.5 mm × 5.5 mm). Two images per strip were captured and evaluated for each experiment.

RESULTS AND DISCUSSION

Ink Transfer

To be able to fairly evaluate how surface roughness and surface energy of both PE-extrusion - coated paperboards and the type of ink influence the printing performance, it is important that the viscosity of the inks and the amount of ink (volume) transferred to the paperboards are constant. This demand is fulfilled for the viscosity, because the inks were prepared to the same viscosity. It is tempting to assume that this demand also is fulfilled for the amount of ink, because it is reported that the transfer in applicator units similar to the anilox roller is volumetric and governed by the open area between the roller and the paper (Salt et al., 2002). However, these researchers studied the transfer of water solutions. No solvent-based solutions were included in their studies.

To estimate the amount of ink transferred to the paper, we measured the copper content in a selection of representative prints and in the inks themselves by using atomic absorption.

Copper originates from the pigment in the ink, and according to the supplier, both inks contained the same pigment but in different amounts. The result of the measurements is shown in Table 1, where the corresponding print density is also given for sake of comparison.

Table 1. Copper content (mg/kg dry sample) in print and ink, and print density on smooth corona-treated PE-extrusion-coated paperboard

Sample identification	Printing pressure, N	Copper g/kg	Print density
Solvent-based ink on paperboard	50	0.023	0.593
Solvent-based ink on paperboard	150	0.023	0.643
Water-borne ink on paperboard	50	0.026	0.711
Water-borne ink on paperboard	150	0.026	0.724
Unprinted paperboard		0.0014	
Solvent-based ink		57	
Water-borne ink		36	

From the data in Table 1 and the data given in "Materials and Methods," we estimated the volume of ink on paper:

Water-borne: 0.61 mL/m^2

Solvent-based: 0.52 mL/m^2

As is evident from this estimation, the volume of ink on paper was higher for the water-borne ink (15%). Table 1 also shows the pigment strength for the water-borne ink was lower than for the solvent-based ink. This suggests that to meet a given print density, more ink (mass) is needed when printing with the water-borne ink.

The print density for all the printed material is shown in Figure 1. The highest print density was obtained with the water-borne ink. This is in agreement with the copper content in the print (cf. Table 1). The print density became higher on the smooth paperboard (Lagerstedt and Kohlseth, 1995; Aspleret al., 2004) as well as at the higher printing pressure (Aspler et al., 1995). The corona treatment did not influence the print density (Mesic et al., 2005).

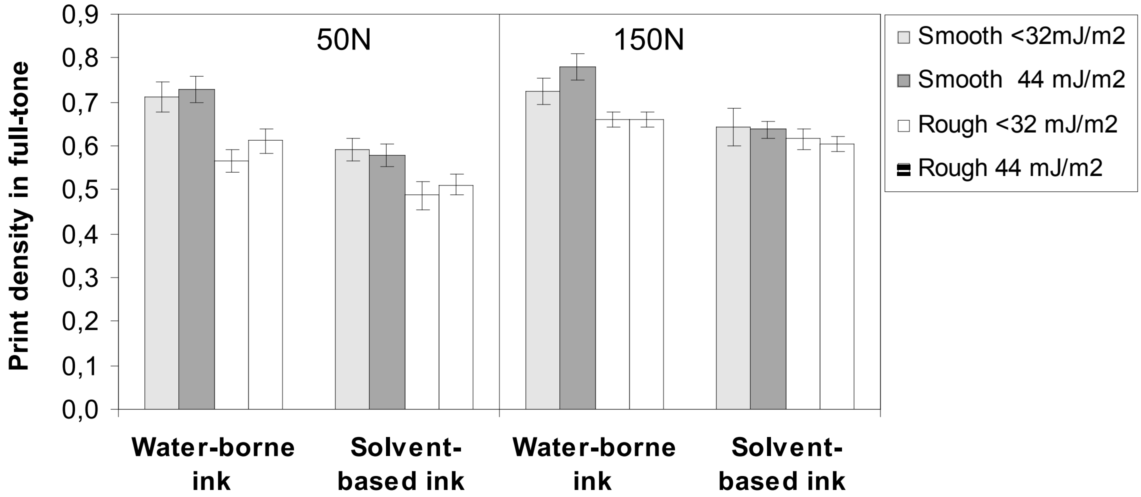

Figure 1. Print density for the printed PE-extrusion-coated paperboards .Error bars indicate standard deviation.

UCAs

The prints were visually inspected in a light microscope with the view to trace the cause of the UCAs—depressions or areas of low surface energy that reject the ink. We failed in this respect. All UCAs appeared the same to us. However, that does not mean that the cause for all UCAs was the same; it only means that we did not manage to trace the cause.

To test the relevance of the instrumental measurement of the UCAs, we performed a visual assessment (rating) of them. Due to the large number of printed samples, the assessment was restricted to the material printed at the lower printing pressure (50 N). Figure 2 shows that the agreement between measured and visually assessed UCAs was good.

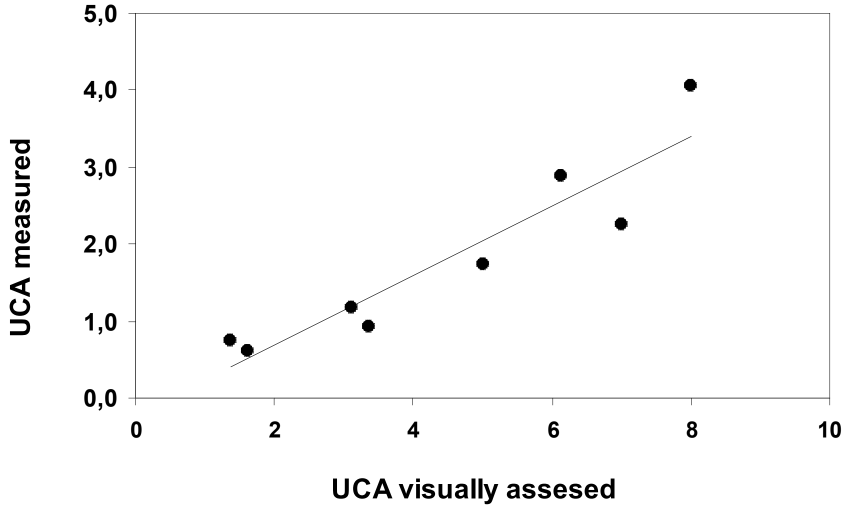

Figure 2. Relationship between measured and visually assessed UCAs.

The UCAs (instrumentally measured) of the printed material is shown in Figure 3. Here it is immediately seen that the material printed with the solvent-based ink exhibited the highest values of UCAs. This is true at both printing pressures, but lower values were, of course, obtained at the higher pressure. However, to draw the conclusion that the solvent-based ink is more prone to impart UCAs than the water-borne ink from this observation is incorrect, because the amount of ink on the paper was not the same. As already said in the previous paragraph, the amount of ink was 15% less for the solvent-based ink, and to be able to correctly assess UCAs, the amount of ink must be constant. Most likely the higher UCAs values for the material printed with the solvent-based ink were caused by the lower amount of ink. Figure 3 also shows that surface roughness and corona treatment affected the UCAs in the same way for both inks. Surface roughness increased UCAs and corona treatment reduced UCAs.

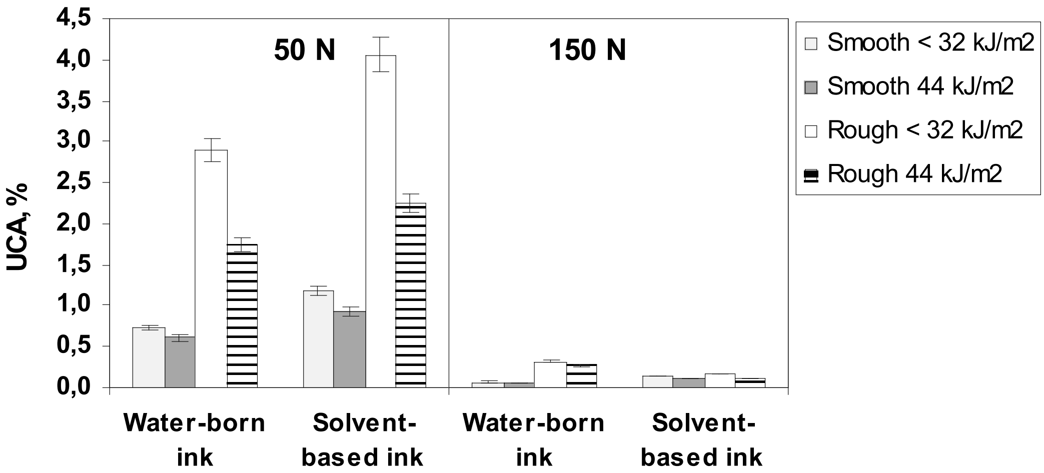

Figure 3. UCAs for the printed material. Error bars indicate 5 % margins.

The conclusion stated above that UCAs for both inks was affected in the same way by the paperboard properties finds support in the nice relationship between the UCAs for the materials printed with solvent-based and water-borne inks respectively (see Figure 4).

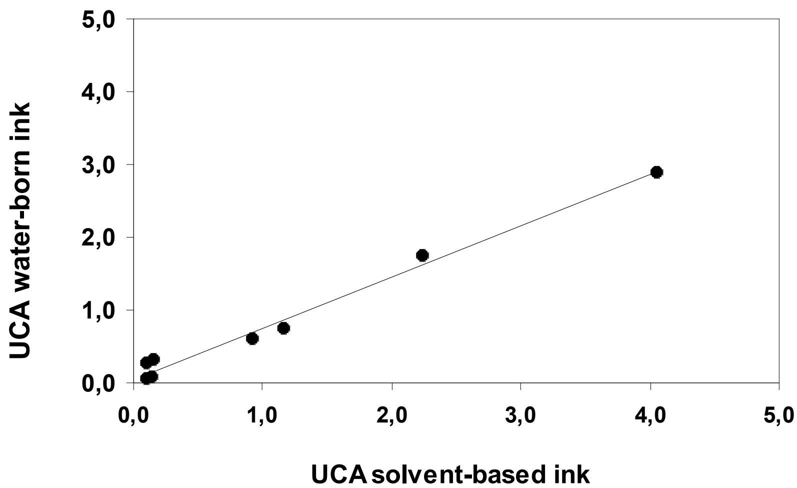

Figure 4. Correlation between UCAs for material printed with water-borne and solvent-based inks.

Ink-Film Thickness Distribution

Mottling is the visual perception of unevenness in print density. This unevenness, in turn, is governed by ink-film thickness distribution and print density. Mottling can be measured both subjectively using a pairwise comparison method (or similar) or instrumentally using image analysis. Johansson (1993) reports good agreement between subjectively assessed mottling and mottling measured using image analysis. The mottling measured using image analysis was expressed as coefficient of variation, which is identical with the standard deviation in print reflectance over the mean reflectance. This ratio is proportional to the standard deviation in print density (Johansson, 1993).

In this work, the objective was to study the effect of paperboard surface characteristics on the ink-film thickness distribution, rather than on mottling. For the printed material examined in this work, the print density was low—at most 0.78. Up to this print density, it can be assumed that ink-film thickness is a linear function of print density. That means that the standard deviation in print reflectance can be used as a measure of the ink-film thickness distribution.

The standard deviation in print reflectance within the 2–4 mm wavelength range is shown in Figure 5. Here it is evident that the ink-film thickness was more uneven on the rough paperboard and that high printing pressure reduced the unevenness. It is also evident that the corona treatment reduced the unevenness slightly, which suggests that the leveling of the ink was improved (Desjumaux and Bousfield, 2000). This is remarkable because the length scale was 2–4 mm Figure 5 also shows that the variations in ink-film thickness developed the same way for both inks. This impression is strengthened by the nice correlation, shown in Figure 6, between the standard deviations in print reflectance for the materials printed with the water-borne and solvent-based inks respectively. In Figure 6, it is also evident the standard deviation was somewhat lower for the material printed with water-borne ink. This is very likely caused by the higher amount of ink on the paper and a more efficient leveling.

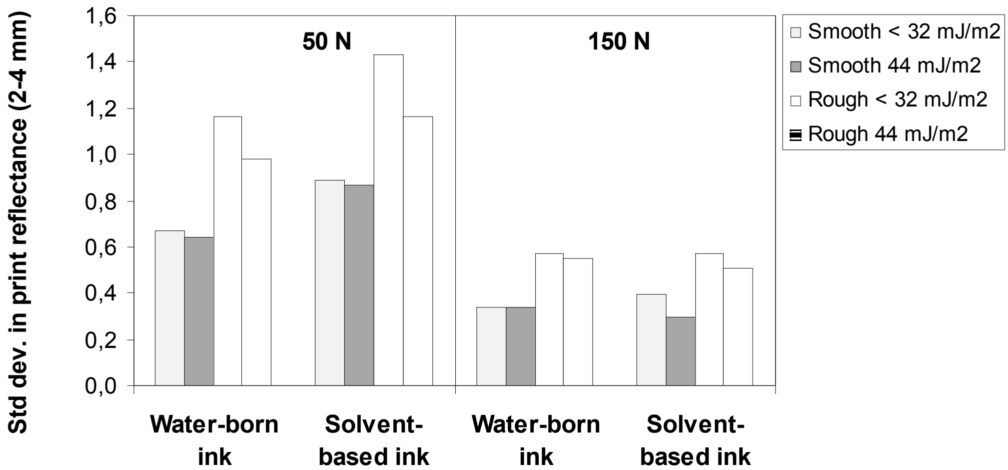

Figure 5. Standard deviation in print reflectance within the wavelength range of 2–4 mm.

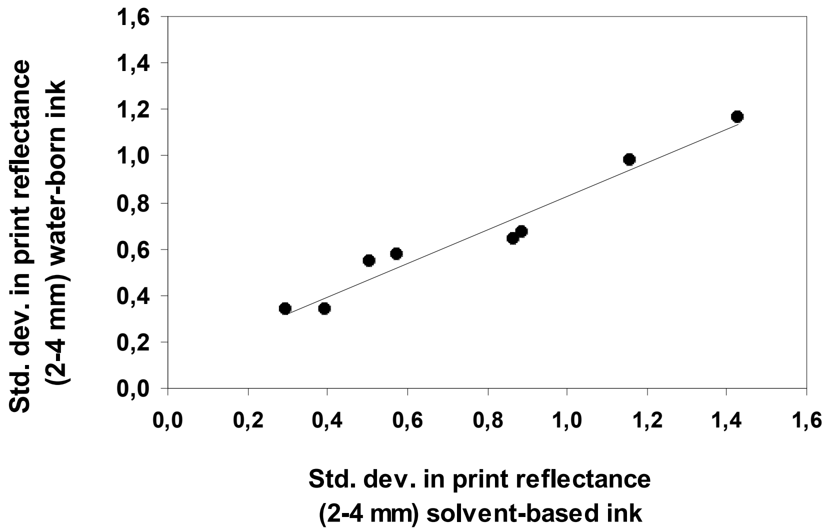

Figure 6. Correlation between standard deviations in print reflectance for material printed with water-borne and solvent-based inks.

It should be pointed out that UCAs does not interfere with the standard deviation in print reflectance within the wavelength range of 2–4 mm reported here, because the length scale of UCAs was significantly shorter (0.5–1 mm).

Print Unevenness on a Submillimeter Level

Figure 7 shows images of fulltone areas printed on the smooth paperboard without corona treatment. The large unprinted spots or areas in the images with an extension of 0.3–0.6 mm are UCAs. The reflectance of the printed area in between the UCAs is—as is evident in Figure 7—uneven, and the appearance of the unevenness is not the same for both the inks. For the water-borne ink, the pattern resembles small, crawling worms or curled thread ends aligned in the direction of the printing. Barros and Johansson (2006) have observed a similar pattern for water-borne ink. For the solvent-based ink, the pattern is grainy and without orientation. The pattern in the printed area in between the screen dots (70%) on the same paperboard exhibits the same pattern (see Figure 8).

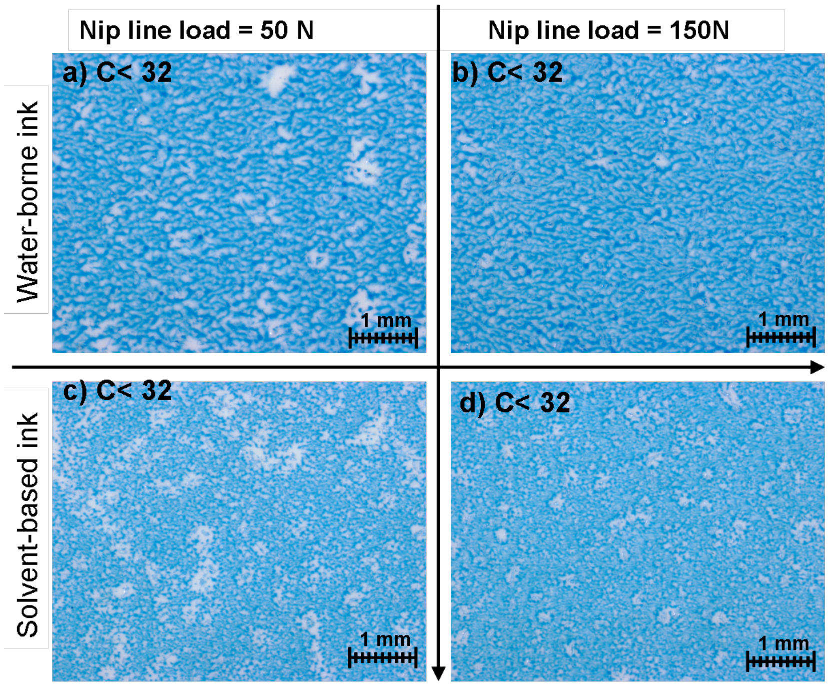

Figure 7. Images of fulltone areas on the smooth paperboard without corona treatment acquired using light microscopy.

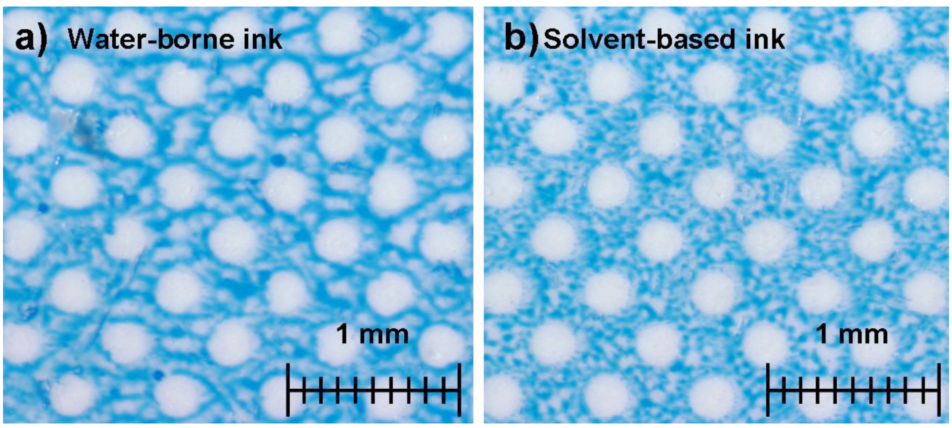

Figure 8. Images of screen dots (70%) on the smooth paperboard without corona treatment acquired using light microscopy.

The pattern in the print on the rougher paperboard, as well as on the corona-treated paperboard, exhibited the same appearance as that for the smoother and untreated paperboard, as shown in Figures 7 and 8.

The variation in print reflectance can be analyzed, not only with respect to level, but also with respect to orientation with help of software used here for image analysis. Figure 9, which shows the standard deviation in print reflectance within the 0.125–0.25 mm range, summarizes this analysis for the smooth paperboard without corona treatment printed with both inks. The analysis showed that the standard deviation in print reflectance was higher in the print direction than in the cross direction for the water-borne ink and that the standard deviation in print reflectance for the solvent-based ink was the same for both directions. This is in agreement with what we can see in Figures 7 and 8.

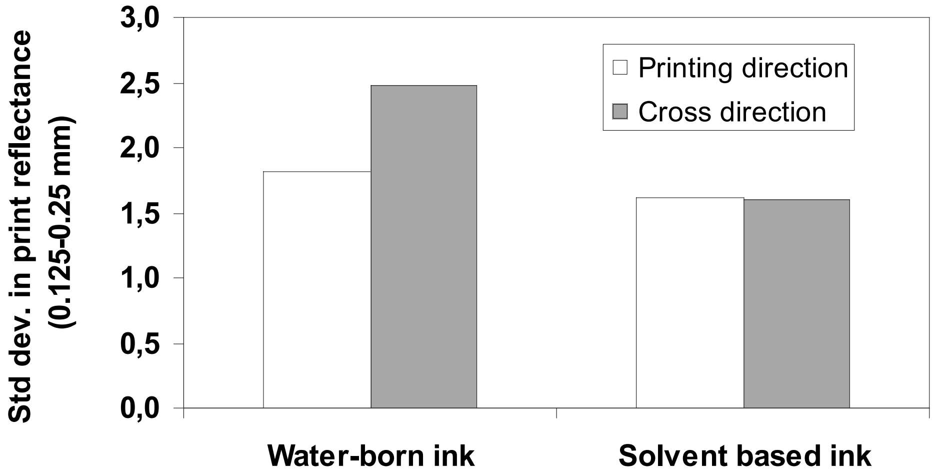

Figure 9. Standard deviation in print reflectance within the wavelength range of 0.125–0.25 mm for the smooth paperboard without corona treatment.

The orientated pattern for the water-borne ink probably reflects the ink-splitting pattern. This pattern is caused by filament formation when the ink splits. The filaments are stretched and broken during the ink transfer. If the broken ends of the filaments on the ink film on the printing substrate do not level out, the printed surface will be patterned (Desjumaux and Bousfield, 2000). Roper (1999) and Gane et al. (1997) report from work with metered size press coating, in which the transfer of the coating color is identical with the ink transfer with an anilox roller, that inelastic filaments reduce the splitting pattern. These researchers also report that high coat weights are prone to form filaments and a patterned surface. This observation is consistent with ours (higher ink-film thickness for the water-borne ink).

The elongation viscosity of the coating color has been proposed to control the splitting pattern in metered size press coating (Isaksson et al., 1998). It is also known from studies of aqueous polymer solutions that different polymers influence the elongation viscosity in different ways (Jäder et al., 2005). The solvent-based ink and the water-borne ink contain different binder systems, which may influence their elongation viscosity. A low elongation viscosity is desired (Schoelkopf et al. 2002).

CONCLUSION

- The ink transfer was significantly higher for the water-borne ink.
- The pigment strength was lower for water-borne ink, so for a given print density, more ink was needed.
- Smoothness and corona treatment reduced UCAs in the same way for solvent-based ink and water-borne ink. High printing pressure also reduced UCAs.
- The variations in ink-film thickness within the wavelength range of 2–4 mm were influenced by the roughness and the surface energy of the paperboard, as well as by the printing pressure, in the same way for both inks. Corona treatment reduced these variations, which show that the inks leveled out on a fairly long length.
- On a submillimeter level, the print with the water-borne ink exhibited a pattern resembling small, crawling worms or curled thread ends, aligned in the direction of the printing. The print with the solvent-based ink was grainy without any orientation.

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