The Interaction between Water and Liner and Newsprint in Flexographic CI-Printing Press

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Keywords

Flexography, Wettability, Newsprint, Linerboard and Printability

Abstract

Printing with water-borne ink in a multicolor printing press subjects the substrate to water, because the water-borne ink contains water. The water in the ink can influence the surface properties, e.g. the roughness and compressibility, and can lead to dimensional changes. On the other hand, water derived from the ink can enhance or reduce some aspects of the final print quality depending on the properties of the substrate. In the present study, the manner in which the print quality of unsized paper substrates was influenced by pre-treatment with water and surfactant solution in flexographic printing was investigated. The experiment was designed to imitate the effects of multicolor printing using water-borne ink, since the water derived from the ink in an early printing unit influences the mechanical, dimensional and wettability properties of the paper and can thus influence the print quality in a later printing unit. This paper complements a previous paper, which showed a reduction of print mottle on a white top liner (with a low water absorptivity and wettability) when water and surfactant solution were applied just before the ink. The substrates investigated in the present paper were standard newsprint and a white top testliner, with high water absorptivity and wettability. The printing trials were performed in a central impression flexographic printing press using two of the six printing units. The first unit was used to apply water and a mixture of water and a surfactant and a second unit was used to transfer water-borne ink. The effects of water and surfactant pre-treatment were evaluated by measuring the print quality and the substrate properties. The pre-treatment by water and surfactant solution showed no effect on print mottle in the case of newsprint or testliner.

Introduction

Flexographic printing with water-borne ink is a printing technique used primarily in the packaging field. Its flexible printing plate and low viscosity inks make it suitable for use on a variety of substrates (Kipphan 2001).

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The use of water-borne ink and flexography for printing newspapers is rather common in the United States and Italy, but in the rest of Europe there is only a limited application of the printing method (Anthony 2001). The environmental advantages of water-borne ink compared to solvent-based inks include a reduction in volatile organic compounds emitted to the atmosphere and toxic substances to the water system, and better working conditions in the plant (Sharpio and Sagraves 1997). The properties of the substrate surface and of the printing form play an important role in ink transfer in combination with factors such as speed and nip pressure. Surface roughness, porosity and water absorbency are important printability properties of linerboards (Zang and Aspler 1995). The roughness of the substrate surface is dependent on and is changed by the pressure applied in the printing nip (Bristow 1982). The surface compressibility is thus as an important property for the printer. The water-borne ink consists of at least 50 % (by weight) of water (Laden and Fingerman 1997), so that the substrate is exposed to water which can affect its properties. The water interacts with fibers and the fiber network. The penetration of aqueous liquids into the paper is further complicated by absorption into fiber walls and this increases the fiber wall thickness, because aqueous liquids break and replace interchain hydrogen bonds in cellulose (Lyne 2002). It has been reported that fibre rising and sheet roughening result from the interaction of water with fibres and with fibrous flocs on the paper surface. These phenomena may be seen in processes like coating and printing where water is applied to the paper (Aspler 1994). The water-induced roughening is related to changes in the cross-sectional shape of the fibres. The most thick-walled fibres have the largest lumen opening even after calendering, and thus make the greatest contribution to the surface roughening (Forseth et al. 1996). The roughening of a substrate by moisture is due more to bulk changes than to surface effects (Toshiharu and Lepoutre 1999). They argued that the bulk structural changes occur as a result of water molecules diffusing into the fiber wall causing e. g. a volumetric expansion in the cross-section leading to a plasticization of the hemicellulose which releases both shrinkage and calendering-induced stresses which strive to keep the fiber cross-section collapsed. Åslund (2004) used an optical method to measure water-induced roughening of paper surfaces and noticed that for substrates containing mechanical pulp there was an almost linear relationship between the relative change in surface roughness and the amount of water transferred. Aspler (1984a) investigated the phenomenon of self-sizing of newsprint and evaluated surfactant application as a possible way of restoring the wettability of newspaper. They came to the conclusion that after self-sizing has occurred surfactant addition can restore the wettability of newsprint and its sorption of water. A more recent study by Aspler et al. (2004) showed that changes in wettability (measured as contact angle) of internally sized solid bleached linerboard had no effect on the transfer and holdout of water-borne flexographic ink. Johnson et al. (2005), on the other hand, showed that the print mottle in full-tone areas on a surface-sized white top liner (WTL) was affected by moisture application in a previous printing unit. The print mottle was reduced by "pre-printing" with a surfactant solution. The same tendency was observed when a large amount (~2 g/m^2) of water was transferred. In the study described in the present study, the effect of pre-wetting on print quality is investigated using a full-scale flexographic CI printing press with the same experimental set up as that described in Johnson et al. (2005). Surfactant solution and water acting as wetting agents were applied in an early printing unit in order to simulate the water applied from ink in a former printing unit/units in a CI-press. The water uptake of the substrates was investigated by means of a dynamic absorption tester, contact angle measurements and $Cobb_{60}$. The prints where characterized with regard to print density, print mottle and dot gain.

The purpose of this paper was to imitate the effects in multicolor printing using water-borne ink, since the water derived from the ink in the early printing units can influence the mechanical, dimensional and wettability properties of the paper and can thereby influence the print quality such as print mottle in the final print. The purpose was also to see whether it is possible to achieve a reduction of print mottle by a pre-treatment with water or surfactant solution, since fulltone areas are an essential ingredient of overall print quality and printers claim that variations in reflectance in solid tones are one problem hindering a satisfying print result.

Materials

Substrate

The trials were performed on standard newsprint (NP) and a white top testliner (TL). The substrates were uncoated. The NP consisted of TMP (Thermo Mechanical Pulp) and a small portion of groundwood spurce pulp bleached with sodium dithionite. A certain amount of starch was added as a retention aid. The NP was glazed on-line in the papermachine in a stack with three hard nips. The TL was produced from 100% post- industrial and post-consumer recycled fibres and was internally sized with starch. The top layer consisted of white post-consumer paper and 6% clay of the total weight. The WTL, described in Johnson et al. (2005), consisted of four layers, two strong outer layers for strength and bending stiffness and two middle layers that gave the liner thickness and density. The print side was a blend of bleached short and long fibres, the reverse side was unbleached long fibre and the middle layers consisted of CTMP (Chemical Thermo Mechanical Pulp) and broke (filling agent and reinforcement pulp). The following substrate properties were measured grammage (SCAN-P6:75), surface roughness (SCAN-P21:67), thickness (SCAN-P7:96), surface roughness and surface compressibility (SCAN-P76:95), $Cobb_{60}$ (SCAN-P12), surface energy (van Oss 1994), equilibrium contact angle with water and pore radius (Webb and Orr 1997). All properties were measured at 23 ºC and 50 % RH except for dominant pore size.

Table 1. Properties of newsprint (NP), testliner (TL) and white top liner (WTL)

	Grammage [g/m^2]	Surface Roughness (Bendtsen) [ml/min]	Thickness [µm]	Surface Compressibility [%]	$Cobb_{60}$ [g/m^2]	Surface Energy* [mN/m]	Contact angle with water at equilibrium** [º]	Pore radius [µm]
NP	45(±0)	100(±10)	70(±0)	2.5(±0.0)	69(±2)	43(±1)	62(±2)	1.5
TL	136(±0)		165(±0)	4.2(±0.2)			47(±2)	1.5

WTL	140(±0)	670(±10) 640(±10)	144(±0)	14.7(±1.5)	134(±2) 24(±2)	49(±0) 47(±0)	102(±2)	1.5

*Calculated using contact angle at equilibrium for water, ethylene glycol and diiodomethane
**Equilibrium contact angle was based on extrapolated data from contact angle versus time

Inks, Water and Surfactant Solution

The TL was printed with a commercial water-borne cyan ink (Scanbrite, Sun Chemical, Sweden), which had a surface tension of 32 mN/m at 23.9°C, according to measurements reported in Johnson et al. (2005). The newsprint was printed with a water-borne cyan ink (Flexonews, Sun Chemical, United Kingdom), which had a surface tension of 39 mN/m at 25°C, according to Wasilewski and Ernest (1986).
The WTL in Johnson et al. (2005) was printed with the same ink as TL. The viscosity of the ink was determined by a Zahn 405/2 (Sheen Instruments, United Kingdom) flow cup according to ASTM D 4212. The viscosity of a liquid when measured with by the Zahn viscosimeter is expressed in Zahn seconds; i.e. the time required for a definite volume of liquid to flow through the orfice at the base of the metal cup. The ink viscosity was kept constant at 30 seconds for Scanbrite and 20 seconds for Flexonews (by addition of water, if needed).
The water used in the printing trials, the Bristow absorption tester, $Cobb_{60}$ and measurements with Fibrodat was tap water taken in Sunne, Sweden. An acetylene diol (Surfynol 402, Air Products Chemicals Europe, Utrecht, Netherlands) was used as surfactant. The concentration was 0.1 % by weight, and the measured static surface tension was 31 mN/m at 20°C (Johnson et al. 2005).

Methods

Flexographic CI-Printing Press

Printing trials were performed in a central impression (CI) flexographic printing press (Soloflex8480, Windmöller & Hölscher, Germany) *Figure 1*. The press has six printing units with five intermediate dryers and a main dryer after the last printing unit. The air circulation and heater were kept at a constant level. The diameter of the CI cylinder was 0.9 meter. The printing speed was either 50 or 100 m/min. Only printing units two and five were utilized. The distance between these printing nips was 1.43 m. Surfactant solution and water were applied in unit two. Ink was applied in unit five. Surfactant solution and water were transferred to the substrate at two levels, low (ca 1 g/m^2) and high (ca 2 g/m^2), using ordinary ink transfer, consisting of a chambered doctor blade, anilox roll and printing plate. An anilox roll with 195 l/cm (cell volume 4-4.5 ml/m^2, cell depth 8 µm) was used to transfer at a low level and an anilox roll with 120 l/cm (cell volume 8 ml/m^2, cell depth 20 µm) was used to transfer at a high level. The ink was distributed with ordinary ink transfer using an anilox roll with 120 l/cm (cell volume 8 ml/m^2, cell depth 20 µm) for TL and 250 l/cm (cell volume 6 ml/m^2, cell depth 15 µm) for NP. The WTL in Johnson et al. (2005) was printed at a printing speed of 50 m/min with the same anilox roll as that used for TL.

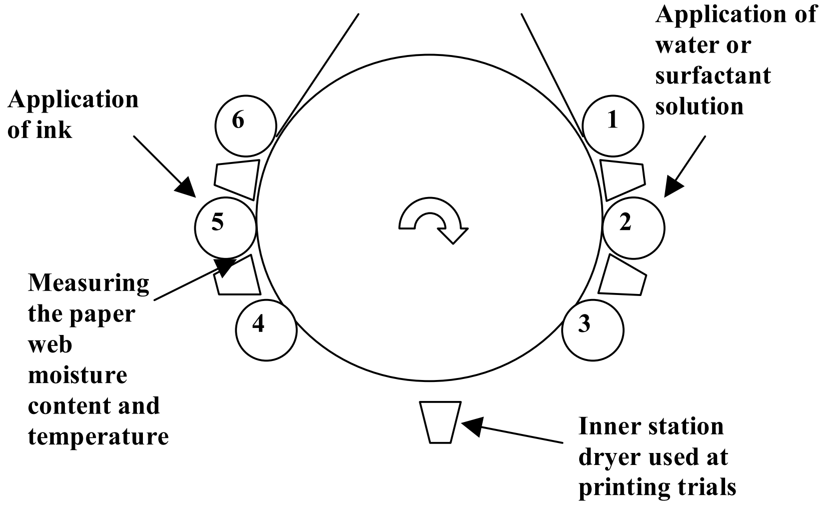


Figure 1. Illustration of the flexographic CI-printing press with six printing units and five inner station dryers.

Three printing plates, BASF Nyloflex 1.14 mm, were used. The plates had a hardness of 78 ºShore A. All the printing plates were exposed using collimated UV-radiation at Flexopartner AB, Sunne, Sweden. One printing plate with a fulltone area was used to apply water or surfactant solution to the substrate in print unit two. The other two printing plates had layouts which consisted of areas with different tone values (30, 50, 70 and 100 %). The screen rulings were 28 l/cm and 32 l/cm with a screen angle of 7.5º. The printing plate used in Johnson et al. (2005) was ACE (BASF, Germany) 1.14 mm with a hardness of 64 ºShore A.

In-line Measurements

Two instruments, MCA 1410 (FIBRO system AB, Sweden) and Raytek ST60 (Sensotest AB, Sweden), were used to continuously record the surface moisture content and surface temperature data of the substrate immediately before applying the ink. MCA is an infrared non-contact moisture sensor and it was mounted at a fixed point at an angle of approximately 20º to the normal to the paper web and about 100 mm before the fifth printing nip. The signal from the sensor was calibrated using TL and NP at a constant temperature (23ºC) with different relative humidities (30-50-80%). The calibration was performed with a metallic background to mimic the substrate's contact with the impression cylinder in the printing press. The temperature sensor, Raytek, is a non-contact pyrometer, which measures the infrared radiation from an object, and thus enables the surface temperature to be calculated. The temperature was measured three times during each run.

Wetting and Spreading

The interaction between the substrates and the water or the surfactant solution was studied by contact angle measurements (Fibrodat 1100, Fibrosystem AB, Stockholm). The surface energy of the substrates was estimated according to van Oss (1994) using three probe liquids; water, ethylene glycol and diiodomethane. A drop (volume around 3-5μl in this study) of probe liquid is placed on the sample surface and an image of the resulting droplet shape is recorded. From these measurements, with the Fibrodat 1100, contact angle (θ), absorption (drop volume) and spreading (drop base diameter) can also be extracted using image analysis applied to images captured by the high speed digital camera of the equipment. The measurements were made on at least 10 samples of each substrate. The contact angle at equilibrium was obtained from data extrapolated from the plot of contact angle versus time. The Bristow absorption tester (Bristow 1967) was used to study the sorption of liquids into the substrates during short time intervals (0-2 sec.). $Cobb_{60}$ was measured to determine the substrates' degree of sizing. The static surface energy of the inks and of the surfactant solution was estimated by the Du Noüy ring method at different temperatures.

Surface Compressibility

Surface compressibility was measured using a Print-Surf tester from Lorentzen & Wettre, Stockholm. The surface roughness was measured at 1 MPa and 2 MPa. The compressibility, *K*, was calculated according to Bristow (1982) as

$$K = -\frac{dR}{dP}$$

where *R* is the roughness under applied pressure *P*. The roughness was measure at different conditions where the humidity was changed in a cyclic manner (nominal values 30 %□50 %□80%□50 %□30% all at 23 ºC).

Print Evaluation

Print Mottle

Print mottle was analyzed using the STFI-Mottling v2.42, STFI-Packforsk AB, Sweden (Johansson 1999). The 1-8 mm range was used. Print mottle was measured on six samples for each sample point, with a sample area of 43.3×43.3 mm^2. The result was reported as coefficient of variation of reflectance.

Print Density and Dot Gain

The optical print density of the printed samples was determined with an L&W Elrepho instrument (Lorentzen & Wettre, Stockholm). The reflectance factors at 600 nm were used. This wavelength was chosen since there is a reflectance minimum at that point coinciding with an absorption maximum in the transmission spectrum of the cyan ink (Johnson et al. 2005). Print density was then calculated from the reflectance measurements measured on six individual samples for each data point. Dot gain was calculated for a tone value of 50 % at 28 and 32 l/cm screen using print density data and the Murray-Davies equation.

Results

Printing Conditions

The conditions during printing are showed in *Table 2*. The measurements were made in the press room. Data were continuously recorded during each trial. In the case of the samples denoted with an asterisk there were problems with the liquid application; the high amount of water or surfactant transported during printing did not reach the paper web satisfactorily, since some liquid "rained" through the press nip. This "rain" was collected and taken into account when the amount of applied liquid was calculated. This may explain the confusing results considering the liquid application for printing on TL at 50 m/min when applying high and low water; the liquid transfer determined in this case was higher when a low amount of water was applied than when a high amount was applied. Generally though, measurement of moisture content showed that the higher application resulted in higher moisture content and the lower application in lower moisture content. Printing TL with low and high surfactant quantities was an exception; at both 50 m/min and 100 m/min there was a higher moisture content at the low compared to the high liquid application.

Table 2. Conditions during printing in the CI-flexographic press.

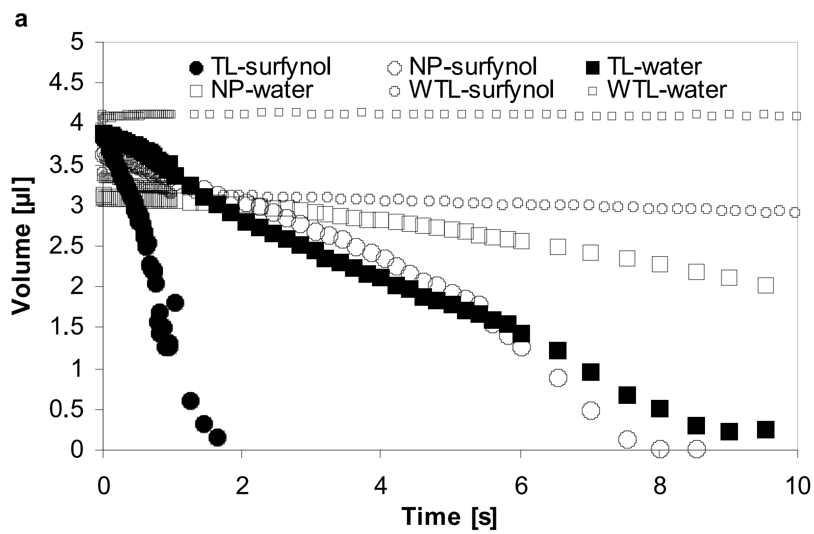
	Press room		**Ink**		**Paper web**		
	Relative humidity [%]	Temperature [ºC]	Viscosity [s]	Temperature [ºC]	Temperature [ºC]	Moisture content [%]	Liquid application [g/m^2]
NP							
50 m/min							
Dry	38.6	23.7	20	22.0	24.8	4.2(±0)	-
Low-water	34.9	24.2	20	22.2	24.4(±0.3)	5.8(±0)	1.2
High-water	37.8	23.5	21	21.5	23.0(±0.1)	6.9(±0)	2.4
Low-0.1 % wt/wt surfynol	32.6	24.1	22	21.2	23.7(±0.2)	5.0(±0.4)	1.1
High-0.1 % wt/wt surfynol	36.0	23.9	21	21.6	23.4(±0.4)	5.8(±1.5)	3.5*
100 m/min							
Dry	36.3	24.6	20	22.2	24.5(±0.1)	4.3(±0.4)	-
Low-water	34.8	24.6	20	22.4	23.7(±0.1)	6.8(±1.1)	1.3
High-water	37.5	23.8	21	21.6	23.2(±0.2)	7.6(±0.7)	2.4*
Low-0.1 % wt/wt surfynol	33.2	24.1	22	21.2	23.6(±0.2)	5.9(±0.4)	1.3

High- 0.1 % wt/wt surfynol	37.7	23.7	22	21.5	23.1(±0.2)	7.0(±1.1)	3.2*
TL							
50 m/min							
Dry	29.9	24.4	31	23.2	23.9(±0.2)	5.0(±0)	-
Low-water	39.5	23.1	30	22.5	22.9(±0.2)	5.0(±0.6)	2.3
High-water	39.7	23.6	30	21.9	22.7(±0.2)	5.4(±0)	2.0*
Low- 0.1 % wt/wt surfynol	29.4	24.3	29	22.4	22.6(±0.7)	6.0(±0.3)	1.3
High- 0.1 % wt/wt surfynol	38.8	23.9	32	21.9	23.1(±0.4)	5.8(±0)	1.7*
100 m/min							
Dry	29.8	24.2	31	22.3	23.9(±0.2)	5.2(±0.3)	-
Low-water	39.5	23.6	30	22.0	22.6(±0.2)	5.8(±0)	1.5
High-water	40.1	23.6	30	21.7	22.5(±0.1)	6.2(±1.4)	2.2*
Low- 0.1 % wt/wt surfynol	30.2	24.0	29	22.0	22.1(±0.2)	7.0(±0)	1.2
High- 0.1 % wt/wt surfynol	39.8	24.0	32	21.8	22.6(±0.2)	6.2(±0)	2.2*

*Less adequate measurement of the transfer with water and surfactant

Wetting and Spreading

The data obtained using the Fibrodat equipment for the substrates interaction with water and surfactant solution are shown in *Figures 2a and 2b*, where a drop of water with a volume of 4 μl was applied to the paper. Figure 2a shows the volume of the drop as a function of time, where a steep negative slope indicates a fast absorption. The fastest absorption was obtained for the surfynol solution on TL, whereas only a slow absorption was observed for water on NP. On both substrates, the surfynol solution was absorbed more rapidly than water, and both liquids were absorbed more rapidly by the TL than by NP. Data for WTL are reproduced from Johnson et al (2005), and figure 2a shows that there was no absorption of the liquids on WTL.



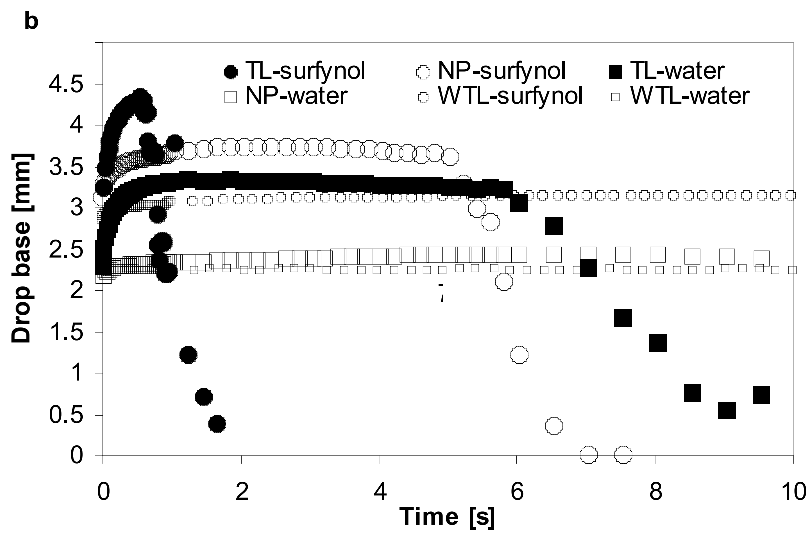


Figure 2a and b. Interaction between liquids and substrate using Fibrodat. a) The volume of a drop of liquid on NP, TL and WTL versus time at 23˚ and 50% RH. b) The base/diameter of a drop of liquid on Np, TL and WTL versus time at 23˚ and 50% RH. Data for WTL are reproduced from Johnson et al. (2005).

Figure 2b shows the base diameter of the liquid drop versus time, displaying three fairly distinct events. First, there is an initial rapid spreading of the drop as the diameter increases. Second, the drop diameter remains constant while liquid is absorbed and, third, the diameter decreases as the drop finally disappears. On NP, the diameter of the surfactant drop was 3.1 mm, whereas that of the water was 2.2 mm. With both liquids, spreading was faster on TL. The surfactant spread and was absorbed by the TL within two seconds, whereas the absorption of water by TL, occurred after approximately 6 seconds. Figure 2b also includes the base diameter behaviour on WTL. A small initial spreading was seen for the surfactant solution, but no significant absorption of the liquids was observed.

The interaction of the substrates with the liquids was also tested using the Bristow absorption tester (Bristow, 1967). The results are showed in *Figure 3*. The TL showed a considerable uptake of both surfactant solution and water, consistent with the results shown in Figure 2a and 2b. NP showed a slower uptake of liquids than TL. Water on NP showed the least spreading and the lowest absorption. At a contact time of one second, water uptake by NP and TL was 40 g/m^2 and 105 g/m^2, respectively. Data for WTL reproduced from Johnson et al. (2005) show a small uptake of both liquids. The uptake for WTL was lower and slower than for NP. A water uptake of 27 g/m^2 at one second was reported.

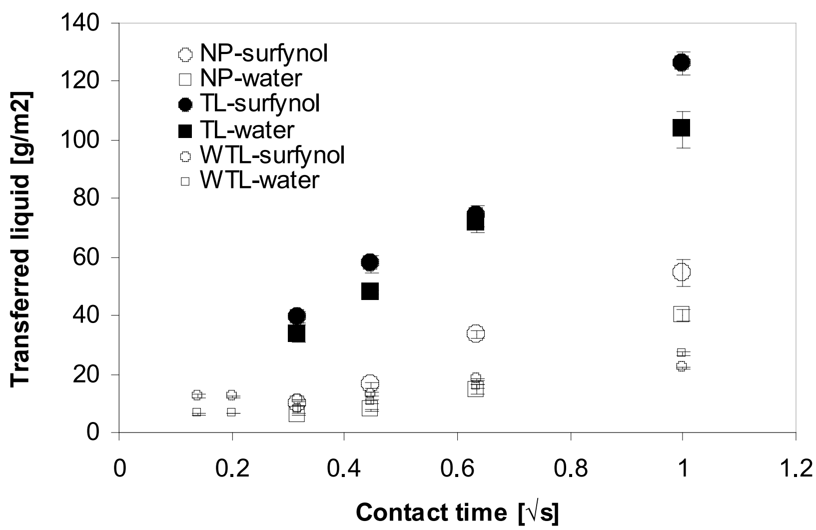


Figure 3. Transferred liquid, water and surfactant solution (0.1 % wt/wt) on NP, TL and WTL at 23° and 50% RH as a function of the square root of time Data for WTL are reproduced from Johnson et al. (2005). Error bars indicate 95 % confidence interval.

Surface Roughness

Figure 4 shows how the Print Surf roughness of NP and TL at 1 MPa and 2 MPa changed with changing relative humidity. With the equipment used, the humidities in the last two stages were 64-54% and 38-36 %, respectively, and not 50% and 30% as planned. The PPS-roughness was lower at a relative humidity of 80% for both substrates and pressures. Normally, the moistening of the paper surface leads to an increase in surface roughness (Forseth et al. 1996).

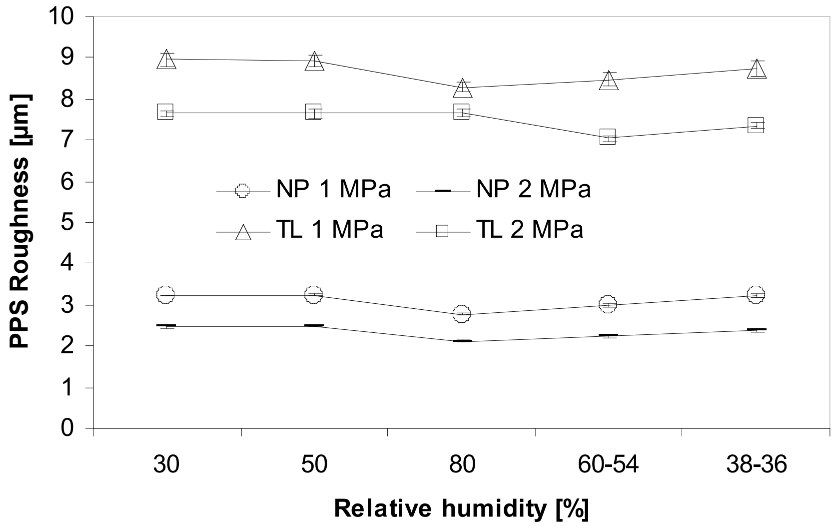


Figure 4. Surface roughness at 23 ºC and different relative humidities for NP and TL. Error bars indicate 0.95 confidence interval.

Print Quality

Print Density

The print density of the full-tone areas on TL is shown in *Figure 5*. Only data for the 28 l/cm screen ruling are presented in the diagrams for print density (Figures 5 and 6) for clarity reasons, since the results for 32 l/cm are very similar and show the same trends. Pre-treatment with both surfactant solution and water on TL tended to reduce the print density, slightly with water and markedly with surfactant, indicating that the paper surface was less prone to accept ink after the pre-treatment. The print speed had no any significant effect on the print density in the full-tone areas.

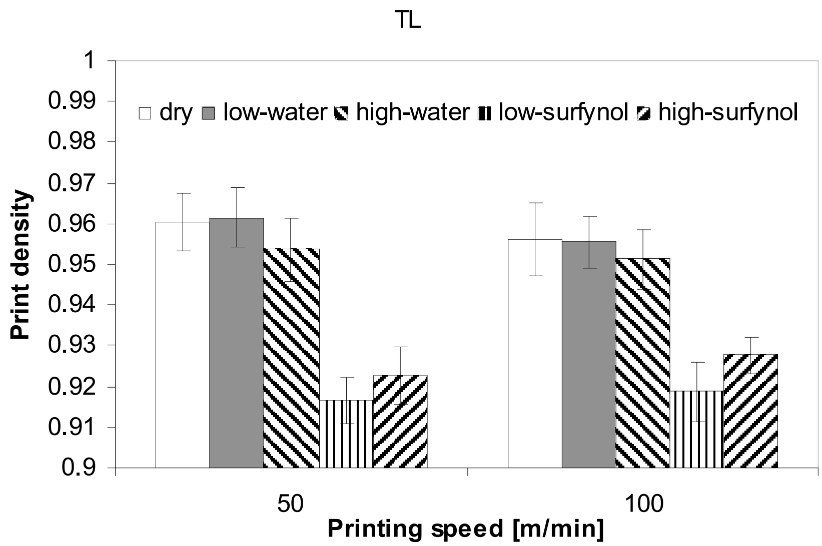


Figure 5. Print density with and without pre-treatment with water and surfactant solution for a full tone area on TL using a screen ruling of 28 l/cm at different printing speeds. Error bars indicate 0.95% confidence interval.

The print density for a solid tone area on NP is shown in *Figure 6*. In this case, the pre-treatment influenced the print density much less than on TL and, in this case, there was a tendency for a low amount of water to increase the print density, which could be interpreted as meaning that the pre-treatment made the surface prone to accept ink. Increasing the printing speed increased the print density, which was reasonable since newsprint presses runs at about 600-800 m/min and the ink was produced for use at a high printing speed. The fact that the print density was higher for TL than for NP, has no significance, since the two papers were printed with different inks using different anilox rolls. The TL-ink had a higher viscosity (30s as determined by the Zahn cup method) than the NP-ink (20 sec, as above.), and this affects the ink transfer (Nordström and Johnson, 2002). Neither high water nor low surfactant application produced low reflectance values (i.e. high print density) in Johnson et al. (2005), which can be interpreted as the paper surface was less prone to accept ink. Further, a low application of water or high application of surfactant gave a lower reflectance meaning that this pre-treatment made the paper surface more ink-receptive.

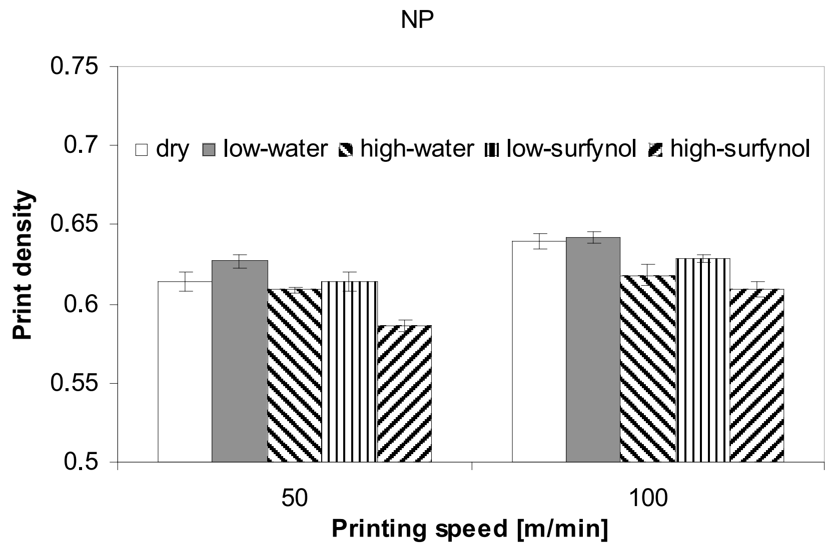


Figure 6. Print density with and without pre-treatment with water and surfactant solution for a full tone area on NP using screen ruling of 28 l/cm at different printing speed. Error bars indicatethe 0.95% confidence interval.

Print Mottle

The print mottle in solid tone (NP, TL and WTL) are shown in *Figure 7*. Also for print mottle, only the 28 l/cm screen ruling is presented for clarity reasons, since the results for 32 l/cm are very similar and show the same trends. The print mottle was only slightly influenced by the pre-treatment with water or surfactant solution on NP. A low application of both water and surfactant showed a small, but insignificant, decrease in print mottle at 50 m/min. TL was not influenced to a any great extent by the surfactant or water treatment. A tendency for a small, but insignificant, reduction of print mottle was seen at 50 m/min and low transfer at 100 m/min. At high transfer, the print mottle was more or less the same as in the dry case. These results differ from those previously presented by Johnson et al. (2005) for WTL, where a reduction (10%) of print mottle was seen on a white top liner when applying a large amount of water or surfactant.

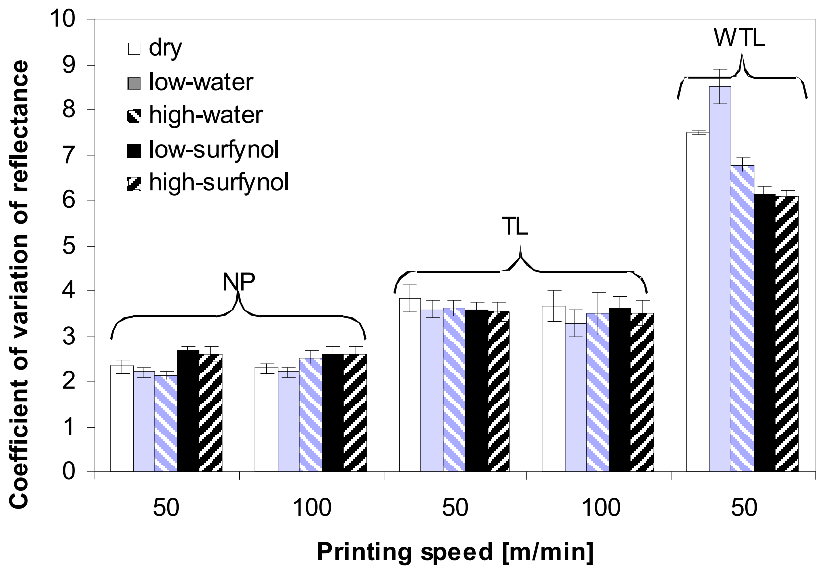


Figure 7. Print mottle (coefficient of variation in print density for the 1-8 mm wavelength range) on WTL, NP and TL treated and untreated with water or surfactant solution at two levels using 28 l/cm screen ruling. The printing speed was 50 m/min or 100 m/min, but only 50 m/min for WTL. The values for WTL are reproduced from Johnson et al. (2005). Error bars indicate the 0.95% confidence interval.

Dot Gain

The absolute dot gain calculated for NP, TL and WTL in the 50 % half-tone areas is shown in *Figure 8*. NP has a higher level of dot gain compared to TL and WTL. The printing speed had no effect on dot gain in the NP and TL cases. Further, neither water nor surfactant solution application influenced dot gain. The dot gain was lower with a screen ruling of 32 l/cm than with 28 l/cm for NP and TL, but is not shown here since they display the same trends and there are no comparable data for WTL.

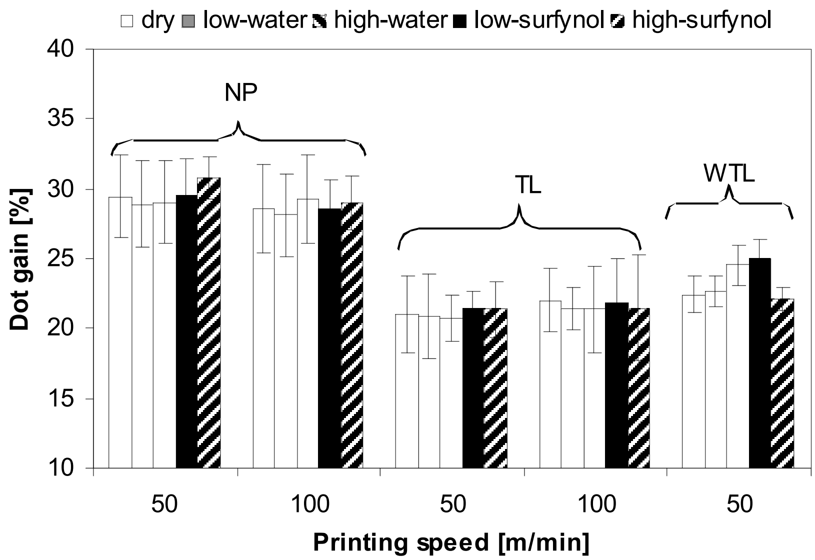


Figure 8. Dot gain as a function of printing speed on NP, TL and WTL with tone value 50 % and screen ruling 28 l/cm at different pre-treatments (water, surfynol) at two levels. WTL data is reproduced from Johnson et al. (2005). Error bars indicate the 0.95% confidence interval.

Discussion

Figures 2a and 2b showed that both the liquids were spread and absorbed on NP and TL, but no spreading and absorption was seen for WTL. This may depend on the sizing of WTL, which prevents the liquids from spreading and penetrating into the substrate. The Cobb-value indicates the degree of sizing. WTL has a value of 24 g/m^2, whereas TL has a value of 134 g/m^2 and NP has a value of 69 g/m^2. The contact angle with water also indicated the more hydrophobic characteristic of WTL, where WTL possessed the highest contact angle (□>90) compared to NP and TL (□<90). The dynamic absorption tester (Figure 3) showed that the fastest uptake and the highest amount of liquid transferred were in TL. The lowest amount of transferred liquid was shown for WTL, which also showed the slowest uptake. The fact that a certain amount of liquid was transferred to WTL using the dynamic absorption tester, even though no observation of absorption or spreading was made, could be attributed to the surface roughness (Bristow, 1967). NP and TL showed a different moisture uptake behavior and the lack of any surface roughening measured by Print-Surf on TL and NP (Figure 4) in different humidity in this investigation could be explained by the moist surface being crushed at 1 MPa and thus appearing smoother than it was and it was not able to be crushed further at 2 MPa. The effect of moisture considering surface roughness measured with Print Surf was probably not confined to the paper surface in these cases. Forseth et al. (1996) used image analysis (SEM) on cross sections of commercial papers and model hand sheets and showed that super-calendered papers containing mechanical pulp fibres exhibit a significant increase in surface roughening when subjected to moisture, whether by water vapor or water. Tosiharu and Lepoutre (1999) used a “GlossMachine” to study the kinetics of the roughening phenomenon through the change in gloss when a paper is subjected to a change in relative humidity. They also investigated handsheets of kraft fibres and discovered that roughening was not merely a surface effect; but also a reflection of bulk changes. The pre-treatment generally decreased print density on TL and NP (Figure 5). It seems that the pre-treatment made the paper surface less ink-receptive. A reason for this could be an increase in surface roughness of the substrates, which can influence and decrease the contact area between the paper and the ink and cause less ink to be transferred (Walker-Fetsko, 1955 and Trollsås 1995). No significant improvement in print mottle in solid tones was seen after pre-treatment with liquids on NP and TL (Figure 7). Both substrates had a low surface compressibility (Table 1). In the previous report by Johnson et al. (2005), pre-treatment with a high amount (~2 g/m^2) of water reduced print mottle on white top liner (WTL). WTL, NP and TL differ in substrate properties such as surface compressibility, $Cobb_{60}$, dynamic absorption of water and contact angle with water. WTL showed no significant water absorption (drop volume) in experiments performed with the Fibrodat equipment, and had $Cobb_{60}$ value showing a high degree of surface sizing, a hydrophobic surface (□>90º for water) and a higher surface compressibility (at least in 23ºC, 50 % RH), although the results obtained with the Bristow Absorption Tester showed that a certain amount of water was transferred to the WTL surface. Surface compressibility plays a part in ink transfer, and a higher surface compressibility leads to a more uniform print result (Hsu 1962, Blokhius and Kalff 1976, and Mangin and Geoffroy 1989).

Conclusions

The study shows that the water derived from the water-based ink from a previous printing unit can affect the print quality in a later printing unit. The measurements made to evaluate print quality showed that pre-treatment with water or surfactant solution had no positive effect on print mottle on the investigated unsized newsprint (NP) or testliner (TL) substrate, which possessed a considerable water uptake capacity. In general print mottle for NP and TL remained unchanged or increased slightly as a result of the pre-treatment. TL together with Scanbrite ink seemed to be more sensitive to pre-treatment with surfactant solution than NP with Flexonews ink; a large reduction in print density was seen when surfactant solution was applied. Pre-treatment with water or surfactant solution had no apparent influence on dot gain or mottle on the printed samples. The favorable effect water or surfactant solution had on WTL considering print mottle in Johnson et al. (2005) could depend on its surface compressibility in combination with the hydrophobic nature of its surface that could affect the (in a subsequent printing unit) wetting properties.

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