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A mission statement

To meet the need for a high quality scientific publishing platform in its field, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries, iarigai, publishes this quarterly peer-reviewed research journal.

The journal will foster multidisciplinary research and scholarly discussion on scientific and technical issues in the field of graphic arts and media communication, thereby advancing scientific research, knowledge creation, and industry development. Its aim is to be the leading international scientific journal in the field, offering publishing opportunities and serving as a forum for knowledge exchange between all those interested in contributing to or learning from research in this field.

By regularly publishing peer-reviewed, high quality research articles, position papers, surveys, and case studies as well as, in a special section, review articles, topical communications, opinions, and reflections, the journal promotes original research, international collaboration, and the exchange of ideas and know-how. It also provides a multidisciplinary discussion on research issues within the field and on the effects of new scientific and technical developments on society, industry, and the individual. Thus, it serves the entire research community as well as the global graphic arts and media industry.

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- Printed decorations
- Printing materials
- Process control

Premedia technology and processes
- Color reproduction and color management
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- Media industry developments
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Contents

A word from the Editor

Nils Enlund
Editor-in-Chief

E-mail: nilse@kth.se

Welcome to the first issue of the Journal of Print and Media Technology Research! In four yearly issues, available both in print and in electronic form, we will provide a new platform for high quality scientific publishing and a forum for information exchange within the ever developing field of print and media technology research.

Traditionally, most of the research in the field of print and media technology has been related to the printing process, its optimization and effects. This is still the fact but, as technology and markets have developed, there has been an upsurge in research that broadens the scope into the wider field of technology for media communication and its related phenomena. The Journal of Print and Media Technology Research will maintain a strong base in print technology and process research but will also welcome scientific contributions that address, e.g., electronic publishing, printed electronics, communication design, environmental issues, technology related market and industry development, and social implications of media use. The journal will happily mix different types of contributions in an attempt to foster multidisciplinary research and scholarly discussion - the world of media communication is changing rapidly and the research community has to not only keep up with, but lead this transformation.

The main substance of the Journal of Print and Media Technology Research consists of scientific and technical papers that are anonymously peer-reviewed by experts in the field. Our aim is to present only quality research work that meets an international scientific and academic standard. High scientific quality is ensured by a selection process supervised by our Scientific Advisory Board, consisting of world-leading scientific authorities in our field. The journal is edited by an Editorial Board with which rests the final decision of acceptance for publication.

At times, the Journal of Print and Media Technology Research will publish special thematic issues, compiled and edited by an invited prominent guest editor.

In addition to the scientific content, the Journal of Print and Media Technology Research will, in separate sections, publish opinions, discussions, event information, industry news, reviews, and topical communications related to our field of research. In this way the journal will serve the entire scientific and academic community as stated in our Mission Statement.

The Journal of Print and Media Technology Research is published by iarigai, the International Association of Research Organizations for the Information Media and Graphic Arts Industries. The General Assembly and the Management Board of iarigai have found that there is a widespread need for a high-quality international scientific publishing platform and have made the decision to use the funds of the organization to establish a new journal. However, the journal is not an official herald for iarigai, but strives to objectively serve the scientific publishing and communication needs of all organizations and individuals interested in contributing to or learning from research in our field.

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The current issue of the Journal of Print and Media Technology Research is number 1, 2012. We have chosen to start publishing at the beginning of a new year in order to produce a full volume of four issues every calendar year. However, as an introductory promotional effort, this preliminary edition is produced already in September, 2011. The regular number 1, 2012 will be issued in the beginning of next year with the identical scientific content.

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We in the Editorial Board hope that you will find the Journal of Print and Media Technology Research interesting, worthwhile and stimulating. We invite you to contribute to the journal by submitting research papers, opinions, news items and comments. Let us all take part in making this a forum for knowledge and information exchange within our multidisciplinary field of research!

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Analysis of color measurement uncertainty in a color managed printing workflow

Peter Nussbaum, Aditya Sole, Jon Y. Hardeberg

Gjøvik University College, Gjøvik, Norway E-mails: peter.nussbaum@hig.no; aditya.sole@hig.no; jon.hardeberg@hig.no

Abstract

Since the recent revision of ISO 12647-2 and ISO 12647-7, specifying the requirements for systems that are used to produce hard-copy digital proof prints, the use of color measurement instruments is even more than before required in the printing industry. Currently, there are many different makes and models of color measurement instruments used in the industry. Therefore, in a modern color managed printing workflow, most of the printing houses use more than one color measurement instrument, typically one instrument in each department (pre-press, press, and post-press).

In this paper, a total of nine commercial spectrophotometers are compared in terms of measurement uncertainty, precision and accuracy, repeatability and reproducibility. The BCRA series 2 ceramic gloss tiles are used to confirm the accuracy and repeatability of these measuring instruments according to the manufacturer's standards. We focus especially on inter-instrument and inter-model reproducibility and discuss the effect of instrument calibration and certification.

For our experimental setup, four different materials are used, one proof print, one commercial print, and one reference print, along with the BCRA series 2 ceramic gloss tiles. In a color managed printing workflow the use of more than one instrument can impair and complicate the color process control due to the color differences between different measurement devices. The effect of the colorimetric measurement errors due to large inter-instrument and inter-model variability between instruments used in different parts of the workflow (e.g. in the printing house, at the customer's site for inspection, and for certification) is discussed and demonstrated in this paper.

Keywords: color measurement, calibration, color differences, print quality assessment, color management

1. Introduction

Recently ISO 12647-2 (ISO12647-2, 2004) and ISO 12647-7 (ISO12647-7, 2007), have defined the colorimetric parameters for process control in the graphic arts, and tolerances for their acceptance. However, the color measurement devices used in a production workflow (from the costumer, designer, prepress, to printing house) may show variations in terms of precision (repeatability, reproducibility) and accuracy of the measurements made. Furthermore, in the context of PSO (Process-Standard Offset) certification, test prints and proofs are printed according to certain aim parameters. The prints and proofs are measured twice, firstly in the printing house with the instrument of the company, and secondly by the certification body to ensure that prints are made within the predefined tolerances. In a practical application, if both measurement devices result in values which qualifies the print or proof as approved, then nobody will question the reliability (precision and accuracy) of the instruments. Similarly if both instruments give values that are outside the given ISO production tolerance. However, if only one of them qualifies the results to pass then you might think of the other one as a false positive. Moreover, it lies in human nature to believe that the instrument, which does not qualify the print or proof as approved is not performing appropriate - without taking into consideration that it might be the proof or print which is indeed produced outside the defined tolerances. However, by improving the instrument accuracy and reducing the inter-instrument and inter-model agreement will contribute in reduce inappropriate considerations. The aim of the presented work is to evaluate the performance of nine color measurement instruments in terms of precision (repeatability, reproducibility) and accuracy. Furthermore, the effect of color measurement variability in a color managed printing workflow will be demonstrated. In particular the result of inter-model agreement measuring colors on paper substrate will be reviewed.

After this brief introduction, we give some more background information in Section 2, by illustrating the problem, defining key concepts, and discussing central references. Then, in Section 3, we describe our experimental setup. In Section 4 we present and discuss our results, before concluding in Section 5.

2. Background

To illustrate how measurement uncertainty in a printing production workflow may cause unexpected discussions, Figure 1 shows a simplified diagram of a practical scenario in which two instruments are used to measure the same target in a color workflow.

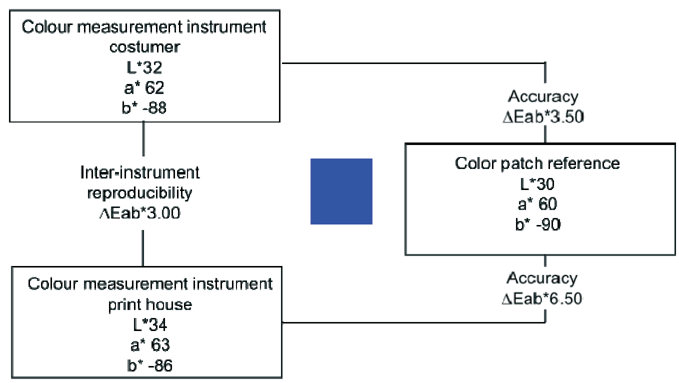

Figure 1: Simplified diagram of a practical scenario using two instruments in a workflow measuring the same target/reference

Given a certain color patch reference and measuring the patch with the color measurement instrument of the customer will result in ΔE^*_{ab} 3.5. Although the inter-instrument reproducibility between the customer and print house measurement devices is ΔE^*_{ab} 3.0, the color difference measured with the print house measurement device on the color patch is almost twice the one measured with the instrument of the customer. Furthermore, assuming having a certain color difference tolerance of e.g. ΔE^*_{ab} 5.0 the result of the print house measurement of ΔE^*_{ab} 6.5 would not be accepted.

According to Berns et al. (2000), measurement uncertainty can be divided into two main categories, precision and accuracy (Figure 2).

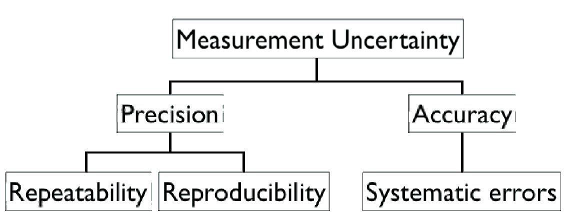

Figure 2: Overview over measurement uncertainty

Precision describes the dispersion of the measurements taken. On the other hand accuracy describes the distance between the measurements taken by the color measurement instruments and the actual target value (Figure 3).

Accuracy is affected by systematic errors, which are errors due to different geometry, detector linearity errors resulting from wavelength.

Precision can be further divided into repeatability and reproducibility. ASTM Standard E 284 (ASTM E284-08, 2008) defines the repeatability as "the closeness of agreement between the results of successive measurement of the same test specimen, or test specimens taken at random from a homogeneous supply, carried out in a single laboratory, by the same method of measurement, operator, and measurement instrument with a repetition over a specified period of time". On the other hand, changing conditions such as the operator, measuring instrument, laboratory, or time, gives a measure of reproducebility.

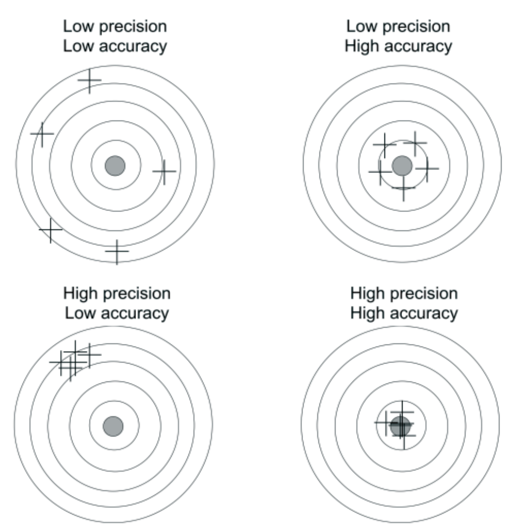

Figure 3: Accuracy describes the distance between the measurement and the target and precision the dispersion of the measurement taken (after Berns' figure on page 95 (Berns et al., 2000))

In the past, various studies and research regarding measurement uncertainties and comparative studies of color measurement instrumentations have been presented. Already 40 years ago Billmeyer (1969) presented a work where he studied the comparative performance of fifteen different color measurement instrument according to their precision and accuracy. Some years later another research conducted by the same author (Billmeyer, Alessi, 1981) concludes that the three instruments tested over en period of seven weeks are essentially equivalent in the precision and accuracy, measuring a large variety of samples, including textile. A slightly different approach has Rodgers et al. (1994) used in his comparative study of color measurement instrumentation were he compared not only the inter-instrument agreement but also the user friendlyness of the software and computer interface, vendor amenability to a long term logistical and maintenance relationship and finally the price. A quality improvement team considered the most critical parameter to be the inter-instrument agreement, followed by the software, the logistical/service relationship, and at last the price. Another comprehensive set of work was carried out by Wyble addressing the evaluation of methods for veryfying the performance of color measurement instrument such as integrating sphere and bidirectional devices. Part I is covering the repeatability issue (Wyble and Rich, 2007) and part II is addressing inter-instrument reproducibility (Wyble and Rich, 2007). However, our main contribution is the analysis of color measurement variability of using a number of different color measurement instruments in a color managed printing workflow.

The specifications, methods and procedures to evaluate the performance of color measuring instruments in terms of repeatability and accuracy are defined in ASTM E2214 (ASTM E2214-08, 2008). Because, the assessment of the instrument's performance and the analysis of the color measurement uncertainty is an important aim of this work, a brief evaluation of the methods is provided here.

Accuracy describes the conformance of a series of readings to the accepted or true value.

Repeatability defines how well an instrument repeats it's reading of the same target over a certain period of time. The assessment of the instrument's consistency can be tested over three periods of time. First is the short-term repeatability which is based on measurements made in succession, second is the medium-term repeatability which can be based on measurement's made over a period of hours and finally the long-term repeatability which is based on measurements made over weeks or longer. The short-term measurements can be performed either with or without replacement of the measuring instrument from the color tile/patch to be measured. When measuring without replacement, the tile/patch is left in place at the instrument's aperture. This approach might be dependent on the instrument technology and the user interface. To obtain the most reproducible results, measurements have been restricted to the central region of the tiles. The color differences are calculated between the mean of the measurements taken and each individual measurement called as Mean Color Difference from the Mean (Berns et al., 2000).

$$MCDM = \frac{1}{n}\sum_{i=1}^{n}\sqrt{\left(L^* - \bar{L}^*\right)^2 + \left(a^* - \bar{a}^*\right)^2 + \left(b^* - \bar{b}^*\right)^2} \qquad [1]$$

Reproducibility is a form of repeatability in which one or more of the measurement parameters have been systematically changed such as the target is different, the time frame of measurements are very long, the procedures or instrument are different or the operator has changed.

Inter-instrument agreement describes the reproducibility of two or more instruments of identical design (In this study e.g. instrument 1-3 have identical design). *Inter-model agreement* expresses the reproducibility of two or more instruments of different design (e.g. instrument 4 and instrument 5). In other words, reproducibility determines the variations between instrument's readings. Instruments, which have the same design the random amount of bias is reduced compare to instrument with different design. The two types of reproducibility can be tested in a similar way. The most common way of testing is pairwise color difference assessment of a series of specimens. Various color difference parameters are used in the literature (ASTM E2214-08, 2008) including the mean color difference, maximum, the root mean square (RMS) color difference or the MCDM. RMS color difference ΔE is calculated as

$$\Delta E_{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\Delta E_i^2} \qquad [2]$$

which is similar to average standard deviation, for N values of ΔE.

3. Experimental approach

3.1 Methods and procedures

To determine the *accuracy* of the used instruments the color difference has been calculated between the measurement average value and the corresponding 'true value'. For each instrument 15 measurements of each tile has been taken in a sequence and the average has been calculated. In this work, the 'true value' is related to the reference values provided by CERAM who is a high-accuracy laboratory and the manufacturer of the used 14 BCRA tiles. Due to practical reasons only the short-term *repeatability* including 15 measurements in sequence and the long-term repeatability with 10 weeks interval of the instruments have been assessed. The sample used for this test is the White BCRA tile and the color differences were calculated according to *MCDM*. It is worth mentioning that before the 15 actual measurements have been conducted to assess the short-term repeatability and after 10 weeks to determine the long-term repeatability a warm up procedure including 25 measurements in a row on its own white standard has been performed. To determine the *inter-instrument agreement* 14 BCRA tiles have been quantified and the mean from each set has been calculated and consequently compared instrument pairwise. To assess the *inter-model agreement* the color difference between the average of 15 measurements of each BCRA sample has been calculated. Thus, the pairwise contrast was compared between the different types of instruments.

3.2 Instruments

In this paper, nine commercial spectrophotometers (one bench - top and 8 hand - held) typically used in the graphic arts industry have been analyzed. Table 1 presents the instruments and their manufacturers's specfications.

Table 1: Overview of the nine instruments (two with valid certification [VC] and seven with expired certification [EC]) used in this work and the corresponding manufacturer's specifications

		Measuring without replacement	Aperture	Measuring geometry	Light source	Inter-instrument agreement	Spectral range and interval	Short term repeatability
Instrument **1 (EC)**	Family **A**	Yes	4 mm	45 °:0°	Tungsten lamp, gas filled, type A light	Mean ΔE^*_{ab} 0.3 Max ΔE^*_{ab} 0.8 on by 12 BCRA tiles ceramics	380 nm to 730nm at 10nm	ΔE^*_{ab} 0.02 (Standard shift from 10 measurements at 10 sec. interval on white)
Instrument **2 (EC)**								
Instrument **3 (EC)**								
Instrument **4 (VC)**		No	2 mm	45 °:0°	Type a	Mean ΔE^*_{94} < 1.0 on by 12 BCRA tiles ceramics	380 nm to 780 nm at 10 nm	ΔE^*_{94} < 0.2
Instrument **5 (EC)**		Yes	4.5 mm	45 °:0°	Tungsten lamp, gas filled, type A light	Mean ΔE^*_{ab} 0.3 on by 12 BCRA tiles ceramics	380 nm to 780 nm at 10 nm	ΔE^*_{ab} 0.02 (Standard shift from 10 measurements at 10 sec. interval on white)
Instrument **6 (EC)**	Family **B**	Yes	4.5 mm	45 °:0°	Tungsten lamp, gas filled, type A light	Mean ΔE^*_{94} 0.4 Max ΔE^*_{94} 1.0 on by 12 BCRA tiles ceramics	380 nm to 780 nm at 10 nm	ΔE^*_{94} < 0.1 (From 10 measurements at 3 sec. interval on white)
Instrument **7 (EC)**								
Instrument **8 (EC)**								
Instrument **9 (VC)**								

Because one of the manufacturers is requesting not to publish their name the names were anonymized by identifying the instruments with instrument 1, instrument 2, … instrument 9.

All instruments represent bidirectional measurement geometries and uses similar light sources. The instrument's aperture size varies from 2 mm up to 4.5 mm. Note, that only two instruments had valid certification (VC) at the time of testing and for seven instruments the manufactory's certification have expired (EC). Nevertheless, the authors were aware of the situation obtaining measurements from 7 instruments, which were not re-certified at the time of the experiment. The 7 (uncertified) instruments are between three and eight years old and not used very often.

However, due to the fact that the presented study is intended to demonstrate the real situation and not reproducing laboratory conditions the choice of the used instruments can be justified. According to the authors experiences from the field it is not uncommon to use instruments in the printing industry, which the re-certification have expired. Therefore the instruments used in this study represent the realistic situation, which is common in the practical production environment.

As stated in ICC (ICC, 2008) when comparing, instruments can be divided into product families which are instruments of the same model from the same manufacturer using equal parameters (e.g. in this work instrument 1-3 can be considered as one family and named 'Family A' and instrument 6-9 'Family B'). In terms of repeatability, or reproducibility, instruments with identical design (inter-instrument) or different design (inter-model) can also be compared.

Different components (such as light source, detector and dispersing element) and their properties consisting of the measurement instrument determine the value of a measured sample. However, it is not the scope of that work to investigate these properties and their contribution to the measurement results. A comprehensive overview of color measurement fundamentals and different instrument components is given by Battle (1997).

3.3 Calibration procedure

Before conducting the measurements, normal warm up and calibration procedures were followed. To warm up the instrument, 25 measurements in a row on its own white standard were made. Consequently, each instrument has been calibrated on its own white reference tile supplied by the manufacturer along with the instrument (absolute white calibration). The absolute spectrum of the white reference tile is stored in the instrument and during the calibration the obtaining spectral response is adjusted so that it matches the stored spectrum. Thus, the instrument's internal software is calculating the spectral reflectance of the measured samples (Beretta, 1999). Instrument manufacturers typically recommend a calibration procedure at least once a day or if numerous measurements are undertaken in rapid succession. Furthermore, if thermal oscillation occur perhaps due to changes in the room temperature or due to the instrument's measurement lamp which can be frequently switched on recalibration is recommended to keep the measurements constant (Wyble, 2004).

3.4 Test procedure on BCRA tiles

To evaluate the performance of the instruments in terms of accuracy, repeatability and reproducibility a series of British Ceramic Research Association (BCRA) Ceramic Color Standards Series II (CCS II) ceramic tiles have been employed (BCRA). In this paper, 14 BCRA ceramic gloss tiles including one Black and one White BCRA ceramic gloss tile were measured and compared to the 'true value' of the BCRA tiles to determine the instruments performance. The measurement procedures were done according to ISO 13655 (ISO, 1996).

3.5 Test procedure on printed substrates

In order to analyze the measurement uncertainties of the color measurement instruments on commercial printed substrates, measurements were conducted on the UGRA/FOGRA Media Wedge CMYK (Schmitt, 2004), which includes 46 color patches (Figure 4).

Figure 4: UGRA/FOGRA Media Wedge CMYK

The Media Wedge was printed on three different paper substrates. The first paper substrate was a hard-copy digital proof print, printed according to the ISO 12647-7 graphic art standards for paper type 1 simulation by a commercial printing house. The second paper substrate was paper type 1 printed by the same commercial printing house aiming the ISO 12647-2 graphic art standards. And the third paper substrate was paper type 5 Altona testsuite reference print (Print & Media Forum, 2004).

Before measuring the color patches of the Media Wedge, warm up and calibration procedure was followed as discussed previously. The Media Wedge was measured three times in a sequence with each instrument. White backing material in accordance with ISO 13655 (ISP, 1996) was used.

3.6 Data collections

All instruments used in this paper reported spectral reflectance factor values from 380 nm to 730 nm with 10 nm interval. Spectral measurements taken from the BCRA tiles and the paper prints were converted to CIEXYZ tristimulus values according to the CIE 1931 2° observer and the CIE Standard illuminant D50 using the method proposed by ASTM 308, Table 1 (ASTM E308-08, 2008). Further details on these calculations are well documented in e.g. Hunt (1998). Furthermore, CIELAB (D50 as the reference white) values were calculated ac-cording to CIE 15 specifications. Colorimetric difference ΔE^*_{ab} and ΔE^*_{94} (as some manufacturers quoted the color difference in ΔE^*_{94}) values were computed between the BCRA reference data and the measurements data obtained using each instrument (CIE, 2004). All measurements in this study have been conducted in the same location and the identical room temperature conditions.

4. Experimental results and discussion

As mentioned before the presented article is aiming to evaluate the performance of color measurement instruments in terms of precision and accuracy and is demonstrating the effect of color measurement variability in a color managed printing workflow.

4.1 Measurement accuracy

As stated earlier ISO defines accuracy as the conformance of a series of measurements to the accepted value for a given sample. In other words how closely an instrument can conform to a certain reference or 'true values'. In this work the reference values have been provided by CERAM who is the manufacturer of the used 14 BCRA tiles.

Figure 5 shows the color difference between each instrument's reading on the BCRA tile and the corresponding 'true value'. Overall, it can be observed that the chromatic BCRA tiles (e.g. Red, Orange and Yellow) produces larger color differences than the achromatic BCRA tiles. Furthermore, all the instruments demonstrate a smaller color differences for the Black tile than the White tile and the dark to light grey tiles show very similar behavior

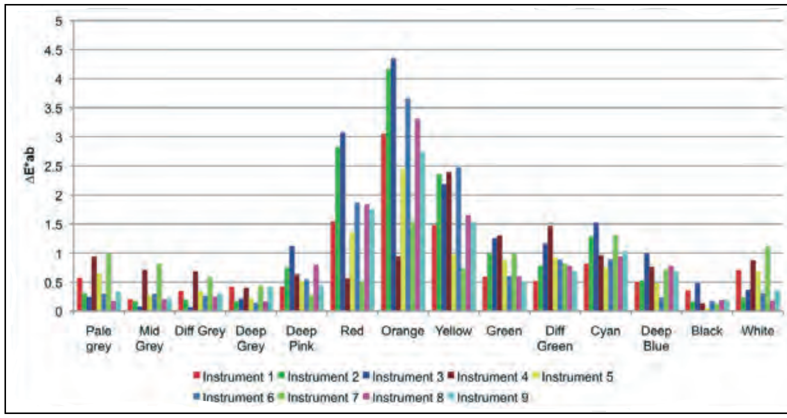

Figure 5: Color difference of nine instruments according to the 14 BCRA tiles reference

The better performance of the instruments on the Black tile suggests good black trap calibration. On the other hand the larger differences on the White tile may indicate that the instruments do not agree very well on the definition of white, which could be traced to the instruments' calibration or missing certification (Table 2).

Table 2: Color difference ΔE^*_{ab} results of nine instruments according to the Black and White BCRA tiles reference

		Black	**White**
Family A	Instrument 1 (EC)	0.35	0.71
	Instrument 2 (EC)	0.16	0.22
	Instrument 3 (EC)	0.48	0.36
	Instrument 4 (**VC**)	0.13	0.87
	Instrument 5 (EC)	0.05	0.68
Family B	Instrument 6 (EC)	0.18	0.31
	Instrument 7 (EC)	0.13	1.11
	Instrument 8 (EC)	0.19	0.18
	Instrument 9 (**VC**)	0.18	0.35

According to the White tile results shown in Table 2 the instruments of the Family A range from 0.16 to 0.48 ΔE^*_{ab}, for the instruments of Family B the differences are even larger, 0.18 to 1.11 ΔE^*_{ab}. This again confirms that some of the instruments didn't comply within the calibration on white reference tile supplied by the manufacturer or this could be a consequence of out of date re-certification. On the other hand, the newest and certified instrument (instrument 4) shows a rather high color difference on the White tile (0.87 ΔE^*_{ab}) whereas the instrument 8 performs the least color difference on the White tile although, the re-certification has been expired a long time ago.

Similar results with rather small color difference can be seen from instrument 2 (0.22 ΔE^*_{ab}). According to the presented results on the White tile, there is no significant evidence whether an expired certification effect the measurement results. Questions like how frequently an instrument is used and how an instrument is treated and maintained by the operator determine the precision of the instrument. However, the authors recommend an appropriate maintenance of the instrument including regular instrument re-certification to approve the obtained measurements.

The poorest performance for almost all instruments results from the measurements of the Red, Orange and Yellow tiles as shown in Figure 6. Except for the instrument 4 the Orange tile produces the largest color difference. Instrument 7 shows the least color differences for these three tiles. Considering the color differences within the product families (instrument family A includes instruments 1-3, and family B includes instruments 6-9) on the tiles Red, Orange and Yellow, there is no obvious trend visible.

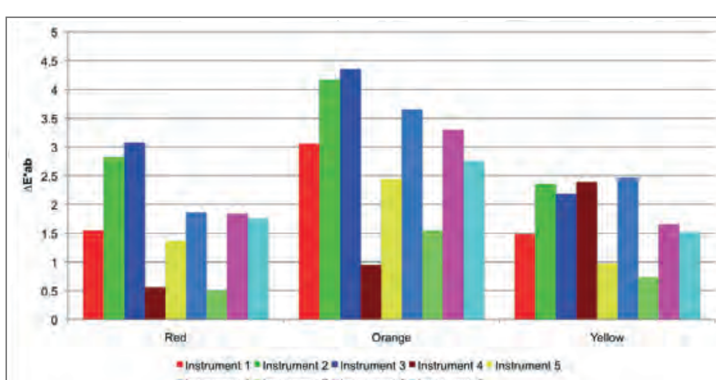

Figure 6: Color difference of nine instruments according to the BCRA tiles Red, Orange and Yellow reference

Note, it is important to consider the inherent physical properties of the BCRA tiles. According to a previous work by Fairchild and Grum (1985) they stated that the BCRA tiles Red, Orange and Yellow can exhibit appreciable thermochromism due to sharp changes in their spectral reflectance curves. Therefore, based on this findings a study by Berns (1988) proposed against using the tiles Red, Orange and Yellow unless the temperature of the tiles at the time of calibration was known and this temperature was maintained both at the location where the tiles would be used and during their measurements.

However, according to the results shown in Figure 6 there is no clear evidence of thermochromism for the instrument 4 and instrument 7 except for the yellow tile. In contrast, the 'master instrument' demonstrates larger color differences due to possibly generating significant heat in the measuring process.

According to Fairchild and Grum (1985), it is important to make sure that the temperature of calibration standards remains constant during their use. On the other hand, there have no significant color changes be observed with small temperature changes around room temperature.

Another way of examining the measurement distribution is to assess the dispersion of the measurements on the CIELAB a*- b*plane. Figure 7 illustrates the measurements of nine instruments on the Orange tile including the distance to the reference itself.

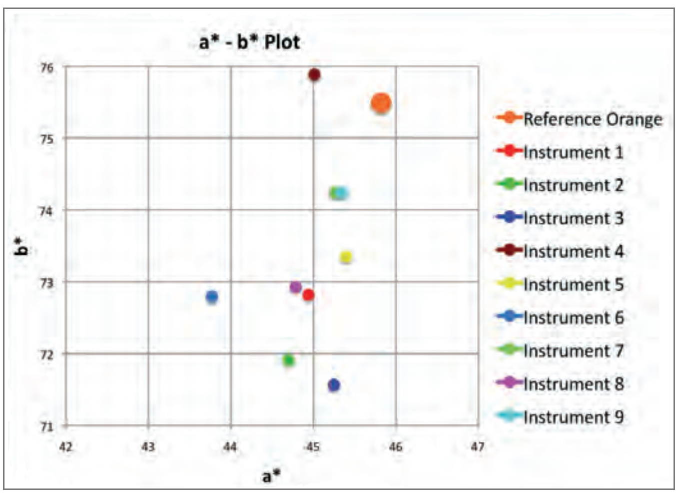

Figure 7:
Measurements of nine instruments on BCRA tile Orange including reference displayed on CIELAB a, b*plane*

Although the results of all measurements show a rather low accuracy, a relatively high precision of the instruments can be considered due to the measurement dispersion, which lies almost in one quadrant in the CIELAB system. Figure 8 shows the measurement value distribution of all instruments on the Orange tile including reference displayed on CIELAB L*, C* plane.

It can be seen that except for instrument 4, the C* color differences comparing to the reference can be considered as rather large. On the other hand, the L* differences can be considered as low. Addressing the product families, it can be noticed that instrument 4 performes best on Orange comparing to the other instruments with different designs.

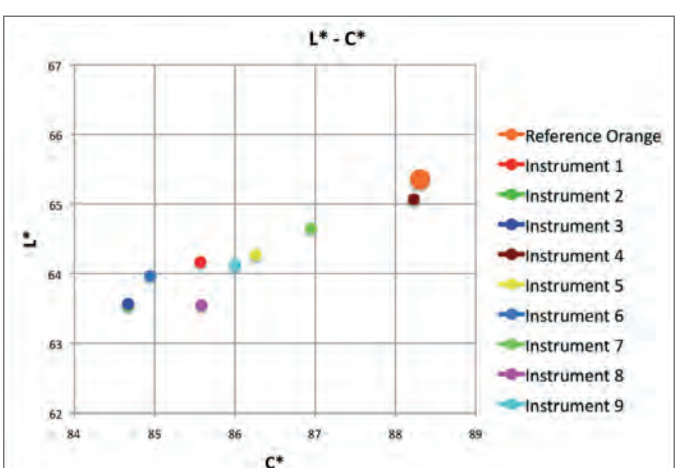

Figure 8:
Measurements of nine instruments on BCRA tile Orange including the reference displayed on CIELAB L, C*plane*

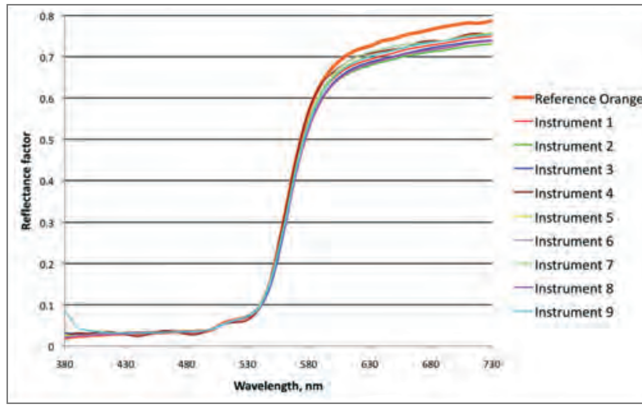

Figure 9: Spectral reflectance measurements of nine instruments on BCRA tile Orange including the reference

Figure 9 illustrates the spectral reflectance of all nine instruments measured on the Orange tile.

It is also clearly noticeable that in the area between 600 nm and 730 nm the dispersion of the measured spectral reflectance by the instrument is rather large. It can be only speculated what the reasons can be for the large dispersion.

One reasonable explanation can be some degree of thermochromism in combination with some white point error due to expired instrument certification. In addition, the reflectance factors of most of the instruments are far below the reference reflectance factor.

Finally, it can be noticed that instrument 4 shows the closest spectral reflectance curve to the reference and again confirms the least color difference on the Orange tile as seen in Figure 6.

4.2 Short-term and long-term repeatability

Table 3 shows the manufacturer's agreement and the corresponding results in terms of the short-term and long-term measurements.

Note, for the long-term repeatability evaluation instrument 1, instrument 6 and instrument 7 were not accessible.

Although the manufacturers do not specify any particular measurement agreements for the long-term repeatability it might be obvious that it is the degree to which the instrument makes identical measurements over a long time. Except for the instrument 1 and instrument 5 on short-term repeatability, all instruments perform results, which qualifies them to pass for the short-term repeatability according to the manufacturer's agreement.

Table 3: Overview over short-term and long-term repeatability performance

Instrument	**Manufacturer's agreement**	**Short-term repeatability**	**Long-term repeatability**
Instrument 1 (EC)	ΔE^*_{ab} 0.02 (standard shift from 10 measurements at 10 sec. interval on white)	Fail	n.a.
Instrument 2 (EC)		Pass	Pass
Instrument 3 (EC)		Pass	Pass
Instrument 4 (VC)	$\Delta E^*_{94} < 0.2$	Pass	Pass
Instrument 5 (EC)	ΔE^*_{ab} 0.02 (standard shift from 10 measurements at 10 sec. interval on white)	Fail	Pass
Instrument 6 (EC)	$\Delta E^*_{94} < 0.1$ from 10 measurements at 3 sec. interval on white)	Pass	n.a.
Instrument 7 (EC)		Pass	n.a
Instrument 8 (EC)		Pass	Pass
Instrument 9 (VC)		Pass	Pass

Note, that the certification for the instrument 1 and instrument 5 has expired. On the other hand, all available instruments have passed the long term repeatability test.

Figure 10 shows the performance of the short-term and long-term repeatability of the instrument 9 and the manufacturer's agreement which is defined with ΔE^*_{94} 0.1 with respect to the mean CIELAB value of 10 measurements on white.

The x-axis indicates the short-term and long-term repeatability variations whereas on the y-axis the color difference is represented. The closer the horizontal mean lines (Oct08 E94 Mean and Jan09 E94 Mean) are, the more identical are measurements and hence better the long-term performance can be considered. It can be seen that both the short and long-term repeatability performs almost equally and within the manufacturer's agreement.

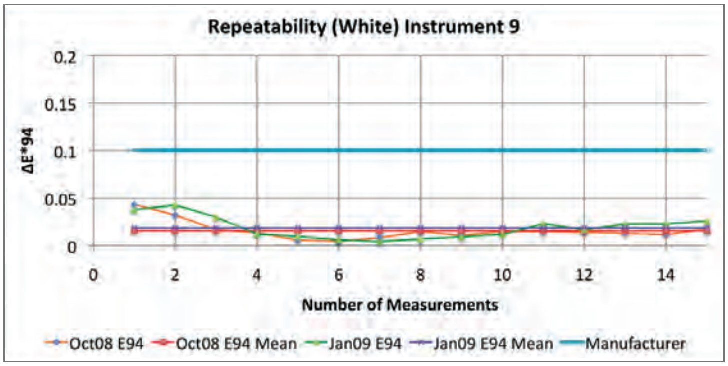

Figure 10: Short-term and long-term repeatability on white including manufacturer's agreement ΔE^*_{94} 0.1 for instrument 9

Furthermore, the graph shows that the largest variations are in the beginning of the measurement sequence. Hence, increasing the number of measurements in the warm up time procedure would increase the total performance of the repeatability for this instrument.

It is worth mentioning that instrument 9 has been recently re-certified by the manufacture. Therefore it can be speculated that the re-certification of the instrument can be the reason for the excellent performance of the short-term and long-term repeatability. For the instrument 5 the manufacturer reduces the short-term repeatability to ΔE^*_{ab} 0.02 units. In Figure 11 it can be clearly observed some minor short-term measurement variations and that the overall repeatability measurements for the instrument 5 exceed the manufacturer's agreement.

Hence, instrument 5 does not conform to the manufacturers' specifications and need to be re-certified. On the other hand, although the manufacturer is not providing any long-term repeatability specification the long-term repeatability can be considered as very good due to the almost identical measurements between the 10 weeks interval.

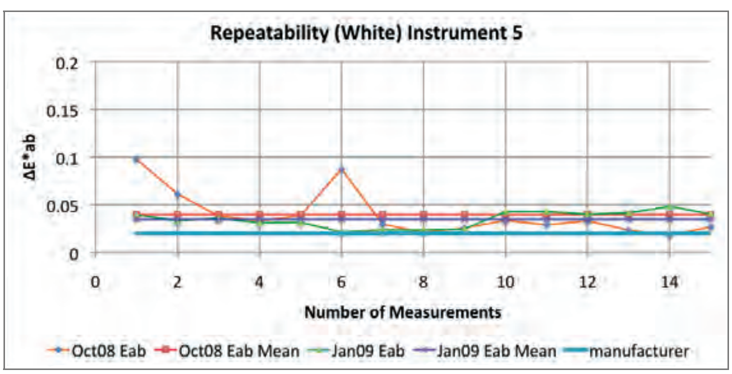

Figure 11: Short and long-term repeatability on white including manufacturer's agreement ΔE^*_{ab} 0.02 for the instrument 5

In this paper, the manufacturer of the instrument 4 has defined the largest repeatability agreement with ΔE^*_{94} of 0.2. Although the mean measurements are strongly inside the manufacturer's agreement as can be seen in Figure 12, the short-term measurement variations are rather large.

The variation is very apparent regardless that instrument 4 is new and recently certified by the manufacturer. On the other hand, the long-term repeatability illustrates almost the same variations. Hence, the long-term repeatability can be considered as acceptable. However, comparing the short-term and long-term repeatability performance with another instrument family the variations are rather large, e.g. the short and long-term variation of the instrument 4 is much larger than the manufacturer's short-term agreement for e.g. the instrument 5. Figure 13 demonstrates the L* versus the measurement number for the three instruments 4, 5 and 9.

Although, instrument 5 and instrument 9 show reasonable repeatability performance in L*, the drift in instrument 4 is very apparent, especially when considering the very short time scale of the measurements.

It can be speculated in which direction the drift would have continued by increasing the number of measurements. The rather large variations might be explained due to instrument technology and the user interface of the instrument 4. The short-term measurements have been performed with replacement/UpDown settings, which means that the tile is not left in place at the instrument's aperture when measuring. Furthermore, it has to be noted that the aperture of this instrument is very small, only 2 mm in diameter. The aperture size in combination with the physical measurement settings, replacement/UpDown may contribute to the obtained measurement variations.

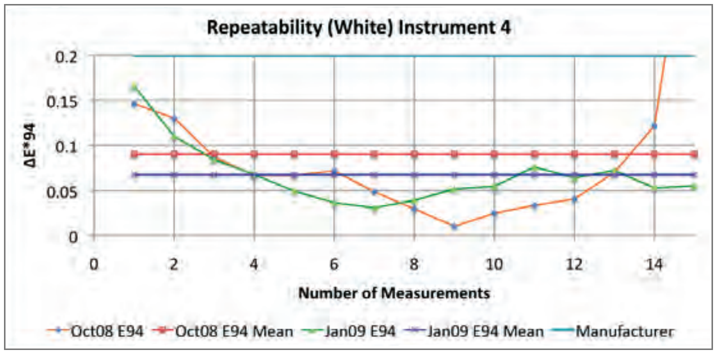

Figure 12: Short and long-term repeatability on white including manufacturer's agreement ΔE^*_{94} 0.2 for the instrument 4

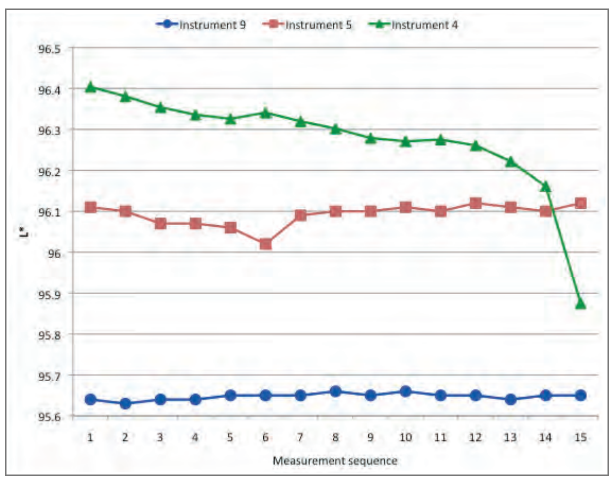

Figure 13: L versus measurement number for instrument 4, instrument 5 and instrument 9*

4.3 Inter-instrument agreement

The instrument manufacturers define certain inter-instrument agreements within their instrument families (Danuser, 2009). For the instrument family B (instruments 6-9) the manufacturer has defined an inter-instrument agreement of mean ΔE^*_{94} of 0.4 and Max ΔE^*_{94} of 1.0 for single measurement mode on 12 BCRA tiles (D50, 2°). Figure 14 demonstrates the pairwise contrast of the inter-instrument agreement within the instrument family B.

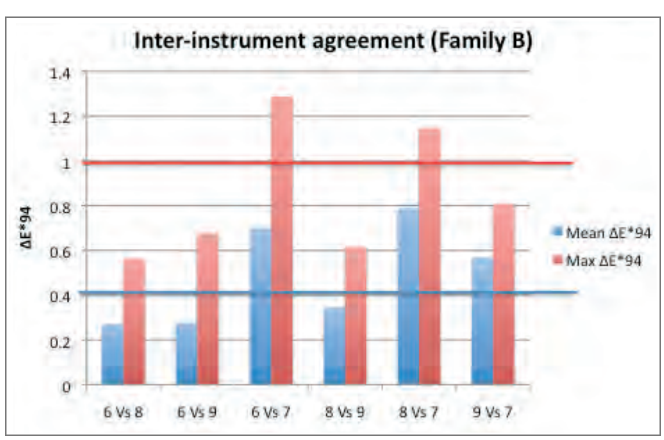

Figure 14: Pairwise contrast of the inter-instrument agreement within the instrument family B, compared to the manufacturer's specifications

It can be seen that instrument 6, 8 and 9 meet the manufacturer's requirements both in terms of mean ΔE^*_{94} < 0.4 and Max ΔE^*_{94} < 1.0. On the other hand for the instrument family A the manufacturer has defined an inter-instrument agreement of mean ΔE^*_{ab} 0.3 and Max ΔE^*_{ab} 0.8 for single measurement mode on 12 BCRA tiles (D50, 2°). Figure 15 shows the pairwise contrast of the inter-instrument agreement within the instrument family A (instrument 1-3).

It can be seen that even though the direct comparison between instrument 2 and instrument 3 is within the inter-instrument agreement given by the manufacturer regarding max and mean ΔE^*_{ab} have been slightly exceeded.

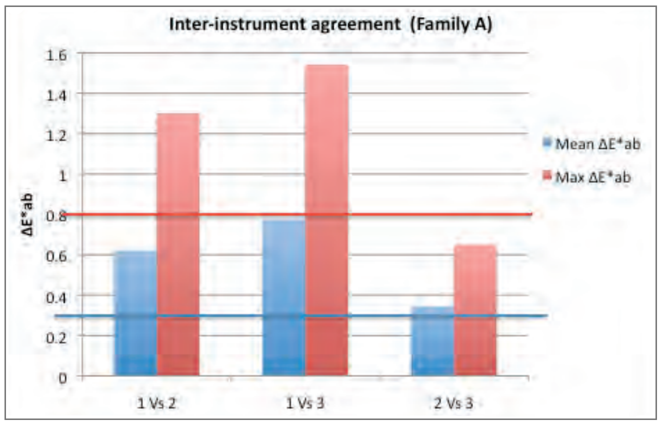

Figure 15: Pairwise contrast of the inter-instrument agreement within the instrument family A, compared to the manufacturer's specifications

The pairwise comparisons between instrument 1 and instrument 2, and between instrument 1 and instrument 3 exceed the manufacturer's requirements distinctly in terms of mean and max ΔE^*_{ab}. Instrument 7 exceeds the requirements noticeably in both the mean value and Max value.

4.4 Inter-model agreement

In order to determine the performance of the inter-model agreement instruments from different families have been compared (instrument 2, instrument 4, instrument 5 and instrument 9). Table 4 shows one color difference ΔE^*_{ab} for each 14 BCRA sample for each pair of instruments.

From each set of color differences, the mean, maximum and RMS color differences and σ, representing standard deviation have been computed. The pairwise contrast where instrument 4 is involved is very apparent with maximum color differences between ΔE^*_{ab} 2.76 and ΔE^*_{ab} 4.46 in the BCRA tiles Red, Orange and Yellow which again is not surprising having seen the accuracy results previously. On the other hand, looking at the pairwise contrast between instrument 5 and instrument 9 the inter-model agreement can be considered as rather good with a maximum ΔE^*_{ab} < 1.

In a previous work conducted by Wyble (2007) the RMS results from a very similar test using three bidirectional instruments show significant larger color differences. Again, the tiles Red, Orange and Yellow were responsible for the largest color differences. Although, the instrument models are unknown, it can be assumed that the difference between the instrument design was larger compared to the instrument design presented in the present work. The dark to light grey tiles show very similar behavior as already seen previously in the results of the accuracy. Generally, it can be observed that dark achromatic tiles result in a significant better pairwise instrument performance than measurement from chromatic tiles with respect to the inter-model agreement.

Table 4: Pairwise contrast of instruments using BCRA tiles

	2 vs 4	2 vs 5	2 vs 9	4 vs 5	4 vs 9	5 vs 9
Pale grey	0.68	0.41	0.16	0.37	0.79	0.56
Mid Grey	0.75	0.31	0.07	0.46	0.79	0.36
Diff Grey	0.79	0.50	0.27	0.38	0.58	0.41
Deep Grey	0.26	0.17	0.28	0.32	0.03	0.33
Deep Pink	1.10	0.46	0.43	0.65	0.99	0.53
Red	2.76	1.48	1.07	1.31	1.73	0.45
Orange	4.27	1.76	1.46	2.68	2.97	0.31
Yellow	4.46	1.44	1.06	3.27	3.82	0.71
Green	0.85	0.31	0.66	0.84	1.25	0.54
Diff Green	1.01	0.56	0.53	1.22	1.49	0.51
Cyan	2.12	0.81	0.26	1.36	1.87	0.61
Deep Blue	0.56	0.06	0.93	0.52	1.38	0.93
Black	0.28	0.18	0.27	0.12	0.14	0.20
White	0.80	0.58	0.30	0.25	0.75	0.52
MEAN	1.48	0.64	0.55	0.98	1.33	0.50
MAX	4.46	1.76	1.46	3.27	3.82	0.93
RMS	2.00	0.83	0.69	1.34	1.66	0.53
STDEV	1.40	0.54	0.42	0.94	1.04	0.18

According to ASTM E2214 (ASTM E2214-08, 2008) the difference between inter-instrument and inter-model agreement can be as large as an order of magnitude which can be confirmed by the presented results with certain pairwise instrument combinations. Note, filter based colorimeter providing tristimulus values only were not part of this study. It can be assumed that a pairwise comparison between instruments obtaining spectral data versus tristimulus data the inter-model agreement can be rather poor. Previously, reports by Rich et al. (2008) have reported rather large color differences considering inter-instrument reproducibility. Furthermore, in his article, the inter-model agreement between the colorimeters and spectrophotometers used for emission measurement has shown a very large color difference.

4.5 Results of print measurements

The following are the results from the measurements performed with seven instruments on three types of substrates (instrument 6 and instrument 7 were not accessible in this task of the work). Firstly, the measurement results on substrate proof will be presented followed by the results for paper type 1 and paper type 5 respectively. To recap, the proof has been created in a commercial printing house, simulating ISO 12647-2 paper type 1. 46 color patches of the UGRA/FOGRA Media Wedge CMYK (Schmitt, 2004) have been measured three times in sequence and consequently the average were calculated.

The mean value (of the three measurements per patch) have been used to calculate the color difference between the target values and each single instrument. The CIELAB target values of the UGRA/FOGRA Media Wedge CMYK are based on print conditions as stated in ISO 12647-2 and the appropriate characterization tables for different paper types are provided by Fogra (Kraushaar, 2008). Table 5 shows the calculated color difference values compared with the CIELAB ΔE^*_{ab} tolerances according to ISO 12647-7. It can be seen that five instruments (instrument 1, instrument 2, instrument 3, instrument 5 and instrument 8) have performed measurements, which are within the acceptable tolerances. The measurements of the instrument instrument 4 and instrument 9 show results, which are far outside the defined tolerances. At first glance, the verdict might be justified. Although instrument 4 performs satisfactorily for most of the colors, the color difference between the instrument's measurement and the reference on the primary color yellow is $\Delta E^*_{ab} > 7$, which is a considerably large color difference. Instrument 9 is the only device, which is using an UV cut filter. Therefore it is obvious that the measurement on the proof substrate exceeds the tolerance due to the concentration of optical brighteners which effects the CIE b* value most (from reference b* -2 to measured b* +4).

Looking at the above measured values, if the proof would have been measured initially in the print shop (where the proof is generated) with e.g. the instrument 1 and then measured by the customer with e.g. the instrument 4 or instrument 9 (which contains the UV Cut filter), then, only the measurement performed by the instrument 1 would have been considered as within the tolerance. However, the customer would not have accepted the proof as approved in a first attempt, as the measurements made by his instrument exceed the tolerances. Using an instrument with a UV Cut filter and an instrument without measuring the proof is inappropriate can be considered as an obvious operator error.

Table 5: Color differences on proof of seven instruments including the CIELAB ΔE^*_{ab} tolerances according to ISO 12647-7:2007 (Orange marked values are outside the tolerance)

	Substrate	Mean	Max	Primaries							Composed grey
	ΔE^*_{ab} 3	ΔE^*_{ab} 3	ΔE^*_{ab} 6	ΔE^*_{ab} 5				ΔH^* (ΔE^*_{ab} 2,5)			ΔH^* (ΔE^*_{ab} 1,5)
				C	M	Y	K	C	M	Y	Average
Instrument 1	1.36	1.39	2.65	1.2	1.52	1.81	1.23	0.76	0.81	0.4	0.48
Instrument 2	1.69	1.28	3	0.9	1.51	0.66	1.2	0.48	1.36	0.04	1.08
Instrument 3	1.52	1.4	3.12	1.43	1.7	0.9	1.38	1	1.59	0.45	0.93
Instrument 5	0.92	1.26	2.46	0.87	1.17	2.05	1.04	0.26	0.86	0.15	0.71
Instrument 8	1.4	1.12	2.67	0.66	1.07	1.48	1.1	0.31	0.92	0.06	0.71
Instrument 9 UV cut	6.34	3.04	6.34	3.27	2.36	2.49	1.68	3.14	2.19	0.33	3.47
Instrument 4	1.4	2.54	7.5	2.96	3.03	7.5	1.36	2.56	0.05	0.71	0.55

It has been observed previously that the instrument 4 results in a large color difference in the primary color yellow when compared with the reference. Figure 16, which shows the measurements of seven instruments on proof substrate on the primary color yellow including reference displayed on CIELAB a*, b* plane can

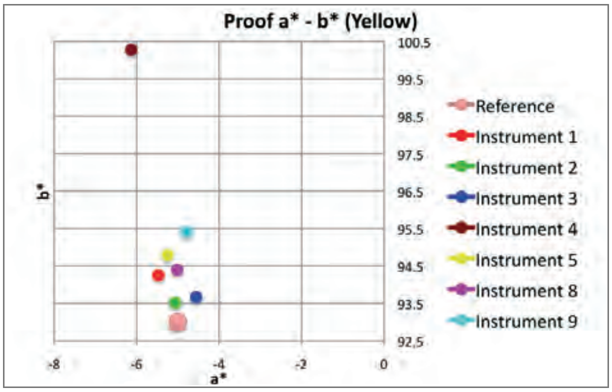

Figure 16:
Measurements of seven instruments on proof substrate primary color yellow including reference displayed on CIELAB a, b*plane*

confirm this finding. However, looking at the precision of the other instruments, the graph illustrates a very small dispersion of the measurements taken. Furthermore, the instrument family A (instrument 1, instrument 2 and instrument 3) can clearly be recognized as the one with the highest precision.

Instrument 9, on the other hand, shows a larger difference in the CIE b* value as seen earlier due to the concentration of optical brighteners in the proof substrate and the measurement with a UV cut filter. Therefore, this large difference can't be considered as a systematic error.

Looking at the measurement results on CIELAB L*, C* plane (Figure 17) the precision within the instrument families can be considered as good.

Although, the difference in L* value between the instrument 4 and the other instrument families is rather small, the difference in C* value can be recognized as very large.

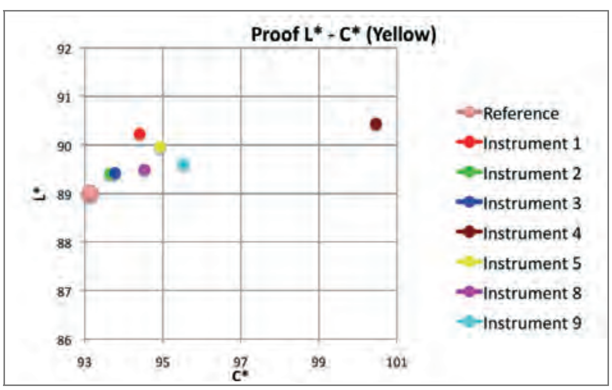

Figure 17:
Measurements of seven instruments on proof substrate primary color yellow including reference displayed on CIELAB L, C*plane*

Similar measurement patterns can be observed in other primary (cyan and magenta) and secondary colors (red, green and blue). Figure 18 shows the measurements of seven instruments on proof substrate on the primary color cyan including reference displayed on CIELAB a*, b*plane.

Overall, it can be observed that the color difference in CIE b* is larger than on CIE a*. It is apparent that the concentration of the optical brighteners in the proof substrate again has affected the cyan measurement with instrument 9.

Although the dispersion of the measurements within the instrument families is slightly larger compared to the primary color yellow, the variations can still be considered as acceptable. It has to be emphasized that in this task the dispersion of the instrument's measurements should be taken into account and not the color difference between the instrument measurements and the reference.

Another way of assessing the measurement results on the solid primary colors is by comparing the inter-model agreement. The observation made in Figure 18 can be confirmed with the CIE ΔE^*_{ab} values in Table 6 which shows the color differences ΔE^*_{ab} on the solid cyan and magenta between each instrument. It is apparent that the instrument 4 and instrument 9 result in the largest color differences on cyan when compared with the other instruments (e.g. Color difference of ΔE^*_{ab} 6.12 between instrument 4 and instrument 9).

This rather poor inter-model performance has already been observed in Table 4 by the pairwise comparison of the two instruments e.g. on BCRA tile Cyan. The differences between instrument 4 and the other instruments range between ΔE^*_{ab} 2.27 and 4.09.

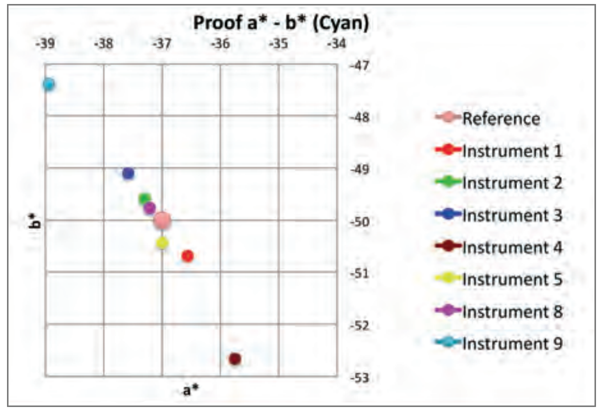

Figure 18: Measurements of seven instruments on proof substrate primary color cyan including reference displayed on CIELAB a, b *plane*

On the other hand, the inter-instrument performance between the instrument family A (instrument 1, instrument 2 and instrument 3) can be considered as acceptable with differences ranging between ΔE^*_{ab} 0.6 and 1.88. Looking at the results of the instrument 5 and instrument 8 the ΔE^*_{ab} is less than 0.8. The upper triangle in Table 6 shows the results on solid magenta, where again, the instrument pair instrument 4 and instrument 9 show the largest ΔE^*_{ab} of 4.16. The least color differences are not within the instrument family A (instrument 1, instrument 2 and instrument 3) itself, but between instrument 8 and instrument 5 (ΔE^*_{ab} < 0.5), as well as instrument 8 and instrument family B (ΔE^*_{ab} < 0.9).

Table 6: Inter-instrument agreement on proof substrate in solid cyan (lower left half of the table) and magenta (upper right half of the table) between all instruments

Cyan ΔE*ab	Instrument 4	Instrument 1	Instrument 2	Instrument 3	Instrument 5	Instrument 8	Instrument 9	Magenta ΔE*a
Instrument 4		2.56	3.48	3.57	2.71	3.16	4.16	Instrument 4
Instrument 1	2.27		1.13	1.29	0.5	0.89	3.24	Instrument 1
Instrument 2	3.5	1.32		0.24	0.8	0.48	3.56	Instrument 2
Instrument 3	4.09	1.88	0.6		0.97	0.7	3.79	Instrument 3
Instrument 5	2.64	0.52	0.89	1.47		0.48	3.18	Instrument 5
Instrument 8	3.28	1.17	0.26	0.84	0.72		3.14	Instrument 8
Instrument 9	6.12	4.13	2.82	2.32	3.67	2.97		Instrument 9

Table 7 shows the color differences ΔE^*_{ab} on the solid yellow and black. Regarding measurements on yellow again, the instrument 4 shows the most significant color differences compared to the other devices with ΔE^*_{ab} > 5.12 which, already has been seen on CIELAB a*, b*plane in Figure 16. On the other hand, instrument 9 shows a much better precision on yellow than what we have seen on the color cyan and magenta.

Table 7: Inter-instrument agreement on proof substrate in solid yellow (lower left) and black (upper right) between all instruments

Yellow ΔE*ab	Instrument 4	Instrument 1	Instrument 2	Instrument 3	Instrument 5	Instrument 8	Instrument 9	Black ΔE*ab
Instrument 4		0.69	0.62	0.87	0.44	0.35	0.57	Instrument 4
Instrument 1	6.06		0.18	0.2	0.4	0.79	1.15	Instrument 1
Instrument 2	6.92	1.18		0.34	0.3	0.66	1.01	Instrument 2
Instrument 3	6.88	1.35	0.53		0.6	0.99	1.3	Instrument 3
Instrument 5	5.56	0.65	1.4	1.43		0.4	0.87	Instrument 5
Instrument 8	6.02	0.89	0.89	0.87	0.66		0.6	Instrument 8
Instrument 9	5.12	1.48	1.93	1.77	0.84	1.04		Instrument 9

The instruments performance on solid black, however, shows measurement results, which are almost ΔE^*_{ab} < 1.0 across all instrument combinations including instrument 4 and instrument 9.

A very similar measurement performance on the BCRA tile black has been observed previously in Table 2. Hence, black seems to be the least critical color considering the precision on inter-instrument and inter-model agreement. Below the results on substrate paper type 1 according to the ISO 12647-2 standard will be presented. The mean values (of the three measurements) have been used to calculate the color difference between the reference given by ISO 12647-2 paper type 1 (white backing) and each single instrument. The calculated color difference have been compared with the CIELAB ΔE^*_{ab} tolerances according to ISO 12647-2.

It can be seen in Table 8 that only three instruments (instrument 2, instrument 5 and instrument 8) give measurement results, which will qualify the print as approved due to the values obtained, which are within the printing ISO tolerance values for all primary colors and the substrate.

Table 8: Color differences on substrate paper type 1 of seven instruments including the CIELAB ΔE^*_{ab} tolerances according to ISO 12647-2 (Orange marked values are outside the tolerance)

	Substrate			**Primaries**			
	ΔE L*±3	ΔE a*±2	ΔE b*±2	ΔE^*_{ab} 5			
				C	M	Y	K
Instrument 1	0.3	1.25	1.41	4.24	1.2	1.86	5.24
Instrument 2	0.07	1.19	0.91	4.55	0.68	2.48	4.8
Instrument 3	0.04	1.42	1.19	4.91	1.05	2.83	5.23
Instrument 5	0.05	1.1	1.41	4.1	1.16	1.89	4.52
Instrument 8	0.15	1.3	1.2	4.16	0.57	2.41	4.02
Instrument 9	0.38	0	3.6	5.35	2.11	2.67	4.0
Instrument 4	0.5	1.79	1.35	3.89	4.07	5.01	4.37

There is evidence of optical brighteners being present in the paper type 1 substrate which affects the CIE b* value when measuring with instrument 9. Therefore using instrument 9 will exceed the measurement value of the substrate above the tolerance value (ΔE b*±2). Moreover, substrates containing optical brighteners affect not only the measurement results on the substrate but also colors in the blue regions when measuring with instrument including UV cut filter. For that reason, the cyan measurement is rather high too.

This observation has been confirmed previously by a work conducted by Radencic (2008) where he concluded that colors which produce extremely high color differences regardless of the instrument were generally recorded on the substrates containing optical brightener and were generally blue in shade. Instrument 1 and instrument 3 show measurement values on black, which just exceeds the color differences tolerances too, as well as instrument 4 in yellow.

Figure 19 shows the measurements of seven instruments on substrate paper type 1 on the primary color cyan including reference on CIELAB a* - b*plane. Overall, a very similar pattern considering the dispersion of the measurement as seen previously on proof can be observed. Also, the color difference in CIE b* is larger than on CIE a*.

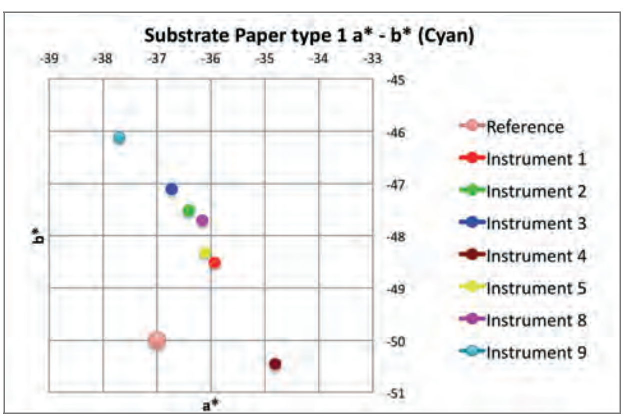

Figure 19: Measurements of seven instruments on substrate paper type 1 primary color cyan including reference displayed on CIELAB a, b*plane*

Table 9 shows the color differences ΔE^*_{ab} on the solid cyan and magenta between each instrument on substrate paper type 1. It can be recognized that the inter-instrument and inter-model agreement on substrate paper type 1 is almost identical to the inter-instrument and inter-model agreement on substrate proof. The same can be stated for solid yellow and solid black for paper type 1 as seen in Table 10.

Table 9: Inter-instrument agreement on substrate paper type 1 in solid cyan and magenta between all instruments

Cyan ΔE*ab	Instrument 4	Instrument 1	Instrument 2	Instrument 3	Instrument 5	Instrument 8	Instrument 9	Magenta ΔE*a
Instrument 4		3.1	3.75	3.76	3.29	3.76	4.5	Instrument 4
Instrument 1	2.33		1.08	1.36	1.45	1.11	2.19	Instrument 1
Instrument 2	3.4	1.11		0.42	0.58	0.19	2.68	Instrument 2
Instrument 3	3.94	1.62	0.54		0.5	0.54	3.09	Instrument 3
Instrument 5	2.55	0.3	0.87	1.39		0.61	2.99	Instrument 5
Instrument 8	3.07	0.96	0.51	1	0.69		2.58	Instrument 8
Instrument 9	5.23	2.99	1.9	1.42	2.72	2.22		Instrument 9

Table 10: Inter-instrument agreement on substrate paper type 1 in solid yellow and black between all instruments

Yellow ΔE*ab	Instrument 4	Instrument 1	Instrument 2	Instrument 3	Instrument 5	Instrument 8	Instrument 9	Black ΔE*ab
Instrument 4		0.97	0.55	1	0.4	0.39	0.66	Instrument 4
Instrument 1	5.42		0.46	0.03	0.89	1.27	1.3	Instrument 1
Instrument 2	6.14	0.89		0.49	0.47	0.82	0.94	Instrument 2
Instrument 3	6.12	1.09	0.42		0.92	1.3	1.32	Instrument 3
Instrument 5	5.58	0.3	0.67	0.94		0.53	0.96	Instrument 5
Instrument 8	6.08	0.89	0.17	0.5	0.63		0.63	Instrument 8
Instrument 9	4.23	1.62	2.06	1.94	1.72	2.03		Instrument 9

And finally the results on substrate paper type 5 according to the ISO 12647-2 standard will be presented.

Table 11 shows the color difference results on substrate paper type 5 of seven instruments. It can be seen that all instruments performed measurements, which will qualify the print as approved due to the values obtainned, which are within the printing ISO tolerance values for all primary colors. Although this paper type 5 should not contain any concentration of optical brighteners (as stated by the paper manufacturer) instrument 9 (UV cut) shows a CIE b* value (2.8) which exceeds just the given tolerance.

Instrument 5 gives the closest readings compared to printing ISO tolerance values.

Table 11: Color differences on substrate paper type 5 of seven instruments including the CIELAB ΔE^*_{ab} tolerances according to ISO 12647-2 (Orange marked values are outside the tolerance)

	Substrate			Primaries			
	ΔE L*±3	ΔE a*±2	ΔE b*±2	ΔE^*_{ab} 5			
				C	M	Y	K
Instrument 1	0.5	0.3	1.7	2.04	3.5	1.44	2.27
Instrument 2	0.0	0.3	1.9	2.65	2.53	1.22	1.55
Instrument 3	0.0	0.4	1.8	2.78	2.18	1.47	1.55
Instrument 5	0.0	0.2	1.0	1.67	2.14	1.68	1.29
Instrument 8	0.0	0.32	2.0	2.44	3.22	1.02	1.47
Instrument 9	0.2	0.25	2.8	2.61	3.76	1.26	1.56
Instrument 4	0.2	0.12	0.8	2.33	3.51	3.72	1.28

Figure 20 shows the measurements of seven instruments on substrate paper type 5 on the primary color cyan including reference on CIELAB a* - b* plane. The dispersion of the measurements is almost identical again with the dispersion of measurements seen on substrate proof and substrate paper type 1.

The inter-instrument and inter-model agreements on the solid primary colors cyan, magenta, yellow and black on substrate paper type 5 are almost identical to the inter-instrument and inter-model agreement on substrate proof and paper type 1 respectively.

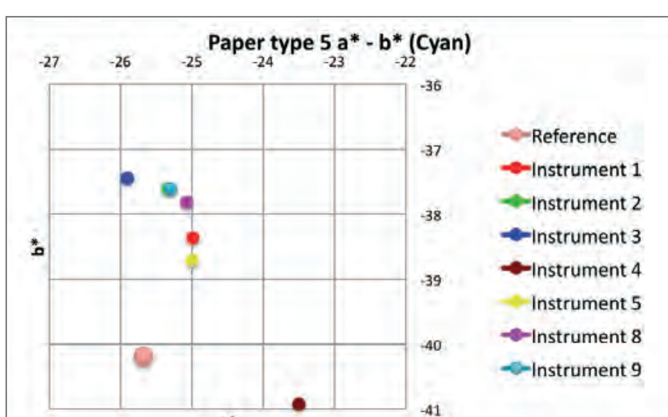

Figure 20: Measurements of seven instruments on substrate paper type 5 primary color cyan including reference displayed on CIELAB a,b*plane*

5. Conclusions

Nine commercial spectrophotometers typically used in the graphic art industry were evaluated in terms of precision and accuracy and the effect of color measurement variability was demonstrated. As stated in ASTM E2214 (ASTM E2214-08, 2008) the most important specification in color measuring instrument is repeatability. According to our results, except of two instruments all others did pass the manufacturer's agreement in the short-term repeatability test. All available instruments did conform to the long-term agreement. On the other hand, as discussed above, there are large differences between inter-instrument and inter-model reproducibility. On one side, the obtained results from the inter-instrument test have demonstrated a reasonable performance among instruments within the same family, as agreed by the manufactures. Nonetheless, the inter-model measurement results have shown, as expected, much larger color differences, especially using instruments from different manufactures. The results of the print measurements did confirm the inter-instrument and inter-model agreement observed before by measuring the BCRA tiles.

As stated previously accuracy describes the averaging of grouping compared to the centre of a certain 'true value'. Considering the accuracy results, overall, it can be observed that the chromatic BCRA tiles (e.g. Red, Orange and Yellow) produces larger color differences than the achromatic BCRA tiles perhaps due to possible thermochromism. Furthermore, all the instruments demonstrate a smaller color differences for the Black tile than the White tile and the dark to light grey tiles show very similar behavior. The larger differences on the White tile may indicate that the instruments do not agree very well on the definition of white, which could be traced to the instruments' calibration or certification status. However, there has no obvious consistency been observed between certified and non-certified instruments in terms of their performance on the White tile.

Consciously, instruments with valid certification and instruments with expired certification have been used in this study to be conforming to the common situation in the printing workflow. It might be expected that instruments with valid certification perform better than instrument with expired certification. Although missing instrument re-certification did not show a significant effect on the measurements, it is highly recommended to maintain the instruments according to the manufactures requirement including appropriate re-certification procedures.

In conclusion, beside of applying only calibrated and certified instruments a further obvious consequence will be the use of only one certain instrument family (same model, same design of instrument from the same manufacturer with the same parameters) in a color managed printing workflow to preserve reasonable color differences. Finally, prevent the use of instruments with different filters (e.g. UV-cut filter) in the same workflow to avoid large errors in measurements. However, in order to improve the colorimetric performance and inter-instrument and inter-model agreement a method of characterizing measurement instruments using colorimetric regression technique has to be considered.

It might be of interest to consider other potential directions for further work in the field color measurement uncertainties. The performance of a number of color measurement instruments (and measurement technologies), in particular for emission purposes (display) in terms of precision and accuracy could be evaluated and the possible consequences of the inter-instrument reproducibility in color managed workflow addressed. Another area within the standardization process in the graphic art industry is the viewing condition set up according to the parameters defined in ISO 3664 (ISO3664, 2009) and ISO 12646 (ISO12646, 2008). To perform the calibration and to verify the appropriate parameters of the ambient light conditions the same hand-held instruments are used attaching a diffuse light measurement head. Therefore, the precision and accuracy for ambient light measurements have to be investigated.

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On developing methods for the identification of relevant paper properties relating to ghosting in heatset offset

Rainer Klein[1], *Martina. Miletić*[1,4], *Patrick Cunningham*[2], *Gerd Meder*[3], *Harald Großmann*[4]

[1] PTS Heidenau, Germany — E-mails: rainer.klein@ptspaper.de; martina.miletic@ptspaper.de
[2] Former PTS, Germany
[3] Mohn media arvato, Germany — E-mail: gerd.meder@bertelsmann.de
[4] TU Dresden, Germany — E-mail: harald.grossman@tu-dresden.de

Abstract

The product quality that can be achieved in offset printing is determined by a multitude of contributing factors. Paper-related influencing variables are functions of the properties of the base paper and coating layer. In addition, print results are affected significantly by many interactions related to the printing process.

Due to the large number of influencing variables of individual properties and in view of their very complex relationships, attempts aimed at quantifying the influencing variables have not yet met with success. The body of knowledge relating to the precise interactions that take place during ink transfer have not yet been thoroughly clarified, and the prerequisites for a scientific solution of offset printing problems such as ghosting and vanishing dots are still lacking.

A European research project has been launched to study the paper-related effects on mechanical ghosting in greater detail. The studies are based on a printing trial in which 18 coated heatset web offset papers (50 to 100 $g\,m^{-2}$) were printed under identical conditions using a "ghosting" printing form, until ghosting phenomena became evident.

Ghosting was evaluated by both visual and metrological means (tool development). The different papers differed clearly in the intensity of ghosting effects. It will be demonstrated that ghosting is caused by a reduction in the area of the printed dots by as much as 10 % on the ghosting side. It will also be demonstrated that ghosting is dependent on the printed image on the non-ghosting side.

The print results form the basis on which to analyze possible interactions between ghosting and important paper properties, the initial results of which will be presented as well.

Keywords: ghosting, web offset printing, runnability, print quality

1. Introduction

Mechanical ghosting in heatset web offset printing is a frequently encountered print-related phenomenon that negatively affects the quality of printed products, increases the production costs and may ultimately cause complaints and dissatisfaction on the customer's side. It can be described as an increase in lightness or tone change on one side of a print which corresponds to the motif printed on the reverse side.

Figure 1 illustrates a practical example of ghosting in heatset web offset printing. The motif on the non-ghosting side (NGS) shows a woman in black with dark hair and a hat, whereas a uniformly grey background is depicted on the ghosting side (GS).

It is evident that the dark parts of the woman on the non-ghosting side cause an undesirable partial brightening of the grey background on the ghosting side.

This is caused by a physical decrease in the size of the printed dots (tone value reduction), so that effects like show-through or print-through can be eliminated as the cause.

Meder (2008) considers this dot size reduction to be caused by the detachment of the paper web from the rubber cylinder as a result of different tack forces acting on the recto and verso sides (as shown on Figure 2).

Motif on the non-ghosting side Ghosting effect on the reverse side (mirrored)

Figure 1: An example of ghosting (Meder, 2008)

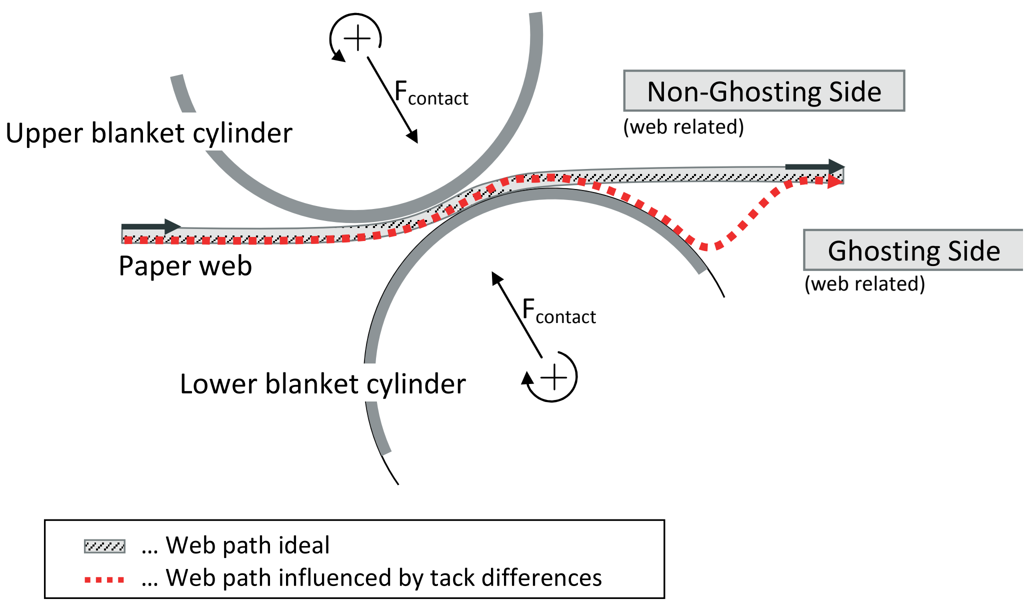


Figure 2: Creation of the ghosting effect - different tack forces acting on the recto and verso sides of the paper web (Meder, 2008)

2. Ghosting - a printing phenomenon

2.1 Factors contributing to the ghosting effect

The cause of the ghosting effect in heatset web offset printing lies in the interaction of paper, printing ink, printing press and print-related parameters and of-course the print motif.

Figure 3 summarizes these variables that govern the complex interactions.

Meder et al. (2008) gave an excellent overview of the essential factors that contribute to ghosting from a press and print-related point of view. Within the scope of the present project, attention is focused on identifying the paper properties which may benefit the development of ghosting during printing, reference being made explicitly to the fact that ghosting cannot always be considered solely to be a paper-related problem.

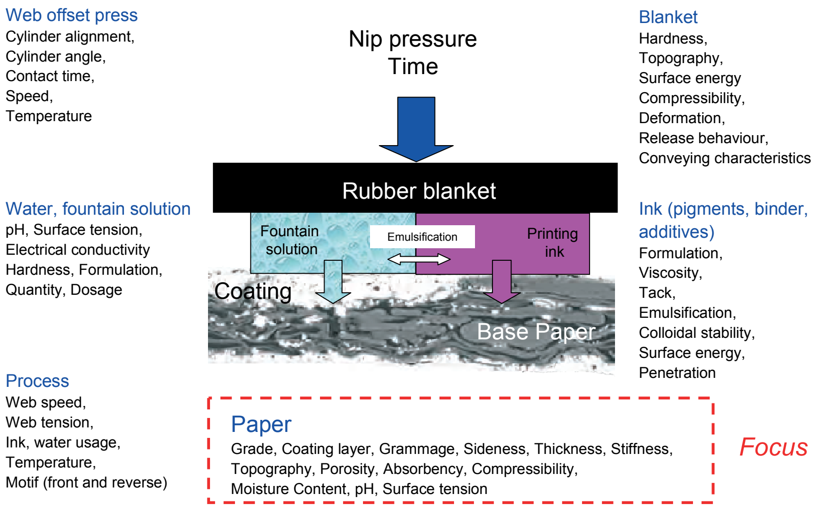


Figure 3: Factors contributing to the ghosting effect (Meder et al., 2008)

2.2 Economic aspects of ghosting

Surveys and interviews with heatset offset print shops showed that ghosting is weighted quite differently by printing shops both with regard to the frequency of its occurrence and to the economic consequences it has. The reason for this lies on the one hand in the wide quality spectrum of printed products and on the other hand on the internal approach taken by the shop when dealing with printing problems. A reduction in ghosting-related problems can have a major economic impact for high-quality products printed in heatset web offset. Figure 4 shows by way of example the amount of waste and its value over the percentage of print jobs involving ghosting problems for a 48/2-A4 printing press. Ghosting currently occurs in 20 % to 25 % of all printing jobs. One concrete example (the data can be extracted from Figure 4) was calculated based on a single washing operation once an hour without any ghosting effect, with every washing operation producing about 600 pages of waste. The appearance of ghosting makes it necessary to increase the number of washing operations from 1 to about 4 times per hour. This causes the waste rate to soar from 600 to 2 400 pages per hour. Furthermore, a decrease in ghosting of only 10 % in printing jobs would decrease the waste by 136 tons per year or 95 200 € per year for the printing press used as the example in Figure 3. If the running costs of the machine are taken into account as well, then the total costs for this machine will be reduced by 125 040 € per year.

Considering that the volume of heatset papers produced in western Europe in 2007 amounted to about 8.75 M tons (approx. € 5 700 M), it is evident that ghosting, even when restricted to high quality heatset products only, is an important economic factor in heatset printing.

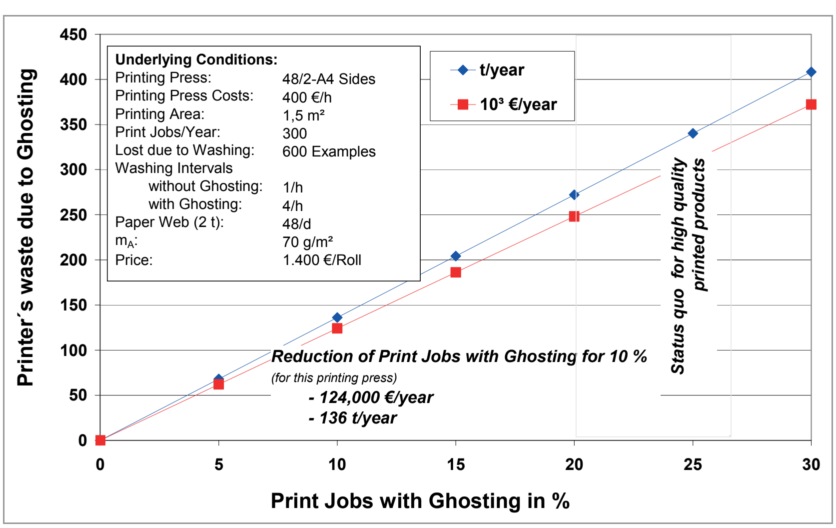


Figure 4: Economic aspects of ghosting

3. Paper selection and printing trials

In order to study the influence of the paper on ghosting, 14 glossy coated and 4 matt coated commercially available heatset papers were selected (Table 1). Their grammages varied between 51 g m^{-2} and 100 g m^{-2} and there were differences in furnish composition. These papers were printed under defined printing conditions on an industrial-scale print trial.

Table 1: Printing paper

Nr.	m_A in g m^{-2}	Surface	Pulp	No.	m_A in g m^{-2}	Surface	Pulp
1	51	gl	wc	**10**	70	gl	rc
2	54	gl	rc	**11**	70	gl	wf
3	60	gl	wc	**12**	80	gl	lwc
4	60	gl	wc	**13**	80	gl	lwc
5	65	gl	wf	**14**	100	gl	wf
6	65	gl	rc	**15**	60	matt	rc
7	70	gl	wc	**16**	70	matt	lwc
8	70	gl	wc	**17**	70	matt	rc
9	70	gl	rc	**18**	80	matt	lwc

gl - glossy; wc - wood containing; wf - wood free; lwc - low wood containing; rc - recycled paper

Printing was conducted on a 24-page MAN Rotoman S printing press (ca. 40 000 pages per hour) with a specially developed "ghosting printing plate", with a linear tone value increase and a screen of 70 L cm^{-1}. Any possibility of minimizing or eliminating ghosting on the press (e.g. register control system) was intentionally excluded.

The printing press was operated by chromatic coordinates /density (K1.5; C1.3; M1.3; Y1.2). The printing inks used for the trial were the Sprint G Next-line from Sun Chemical. Once the defined chromatic coordinates/print densities had been achieved, the rubber blankets were washed and a zero print (run = 0) was drawn out of the production line. Printing was continued until ghosting became visual (approx. 8 000 - 16 000 impressions), but to a maximum of 20 000 impressions. Samples were taken from the production run for each paper every 2 000 impressions.

4. Evaluation of ghosting

4.1 Printing plate - selected elements

Figure 5 shows an excerpt from the overall printing plate containing many elements, all of which are basically designed such that stripes with a constant tone value are located on the ghosting side and tiles with ascending tone values are located on the non-ghosting side.

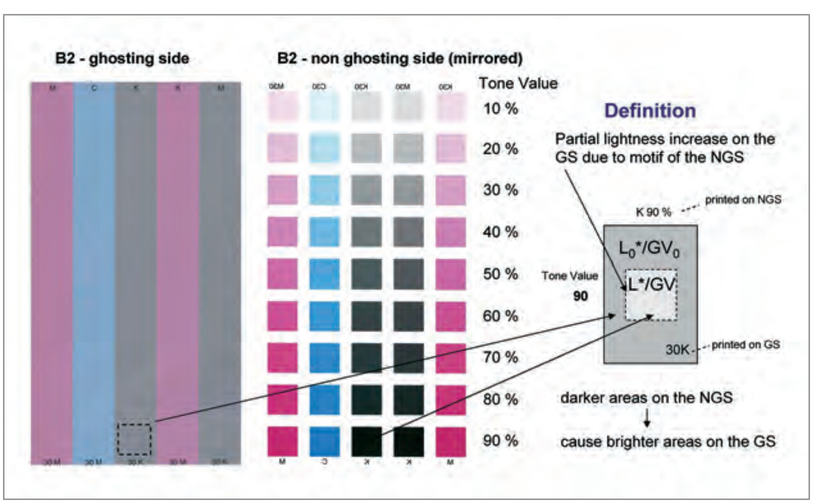


Figure 5: Left: segment on the ghosting printing plate - element B2 (Meder, 2008); Right: definition of ghosting

The five strips on the ghosting side have a target tone value of 30 % and represent three of the four basic colours. The color yellow was excluded as ghosting was generally not found in this color. Tiles with tone values rising in 10 % increments from 10 % to 90 % are located on the non-ghosting side. Both sides were therefore printed using both identical inks and different combinations of inks. This arrangement was chosen in order to be able to differentiate between ghosting originating within a single printing unit (direct ghosting) from ghosting arising in a subsequent printing units (indirect ghosting).

4.2 Evaluation of ghosting

4.2.1 General aspects

Evaluation of ghosting can be conducted:

- visually,
  - qualitatively,
  - semi-quantitatively,
- metrologically,
  - spectrodensitometrically (L* - value),
  - scanner-based evaluation

Print density and lightness are conventionally measured using densitometers / spectrophotometers. In this case, lightness and density were measured on the GS in the areas where the tiles of the NGS and the bridges between them are located (the bridges do not impair the printed image on the ghosting side) (Figure 5). Good concurrence was found between visual and metrological evaluation and due to the higher objectivity of the measuring equipment; only the metrological results will be presented in the following sections.

4.2.2 Scanner-based evaluation of ghosting

The number of printed samples that were to be evaluated was enormously high and would have required a great amount of time even if lightness and density were only to be measured by spectrophotometry. A scanner-based method for the evaluation of the printed samples was developed for this reason. Five printed samples were scanned in each case in colour mode at a resolution of 1 200 dpi. The images obtained were then evaluated by image analysis, the following parameters being obtained for the ghosting side:

- Average grey value (GV) of the tile area (NG) on the GS;
- Equivalent circular diameter of the printed dots;
- Mean grey value of the printed dots.

In order to be able to compare the amount of ghosting on the individual papers with one another, the parameters listed above were standardized for an area with a tile coverage of 10 % on the non-ghosting side.

Figure 6 illustrates the development of the ratio of the mean grey value (GV/GV_0) over the increase in tone value of the tiles using field B2 as an example 30 K-K (30K - tone value on the GS 30 %, ink: black; NGS: ink: black) after 18 000 impressions.

Figure 6 shows both the curves of the five measured samples and their averages in the form of the ratio of the mean grey values. A ratio greater than 1.0 implies a lightness increase on the GS - i.e. the appearance of ghosting, whereas values less than 1.0 imply a decrease in lightness. It is obvious that in this example, ghosting begins at a tile tone value of 40 %, rises steeply to the 1.04 level and then declines slightly. The cause of this increase or decrease in lightness is the partial change in the size of the printed dots on the GS which is shown in Figure 7 as the equivalent circular diameter over the length of the printed strip.

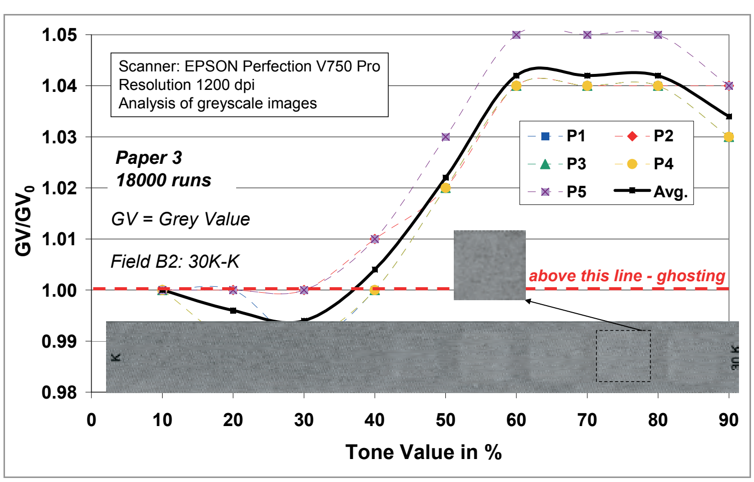


Figure 6: Grey value parameter (GV/GV_0) as a function of the tone value of the non-ghosting side of a print

At a tile tone value of 10 % (NGS), the dot diameter amounts to approx. 83 µm. At a tile tone value of 50 %, it amounts to approx. 80µm, and the tile tone value continues to decrease further until it reaches an average level of 76 µm. This corresponds to a reduction in dot size of 8.5 % and is the cause of lightness increase. It is evident that the dot size on the GS in the area of the bridges between the tiles (NGS) amounts to 83 µm which in turn corresponds to a tone value of 10 %. Furthermore, the dot diameter in the tile area (NGS) is not constant, but rather increases constantly in the printing direction (2-5 µm). It should be noted in this context that the absolute area of the printed dots can only be estimated with medium accuracy at a scanner resolution of 1 200 dpi (21 x 21 µm^2 per pixel). This means that, as resolution increases (e.g. microscopic dot analysis), the absolute dot area will increase as well. This can be ignored, however, since only the relative change in the size of the dots as a function of the motif of the NGS is significant when evaluating ghosting.

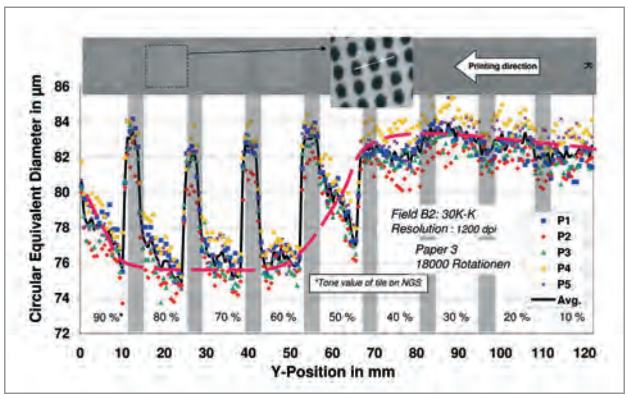
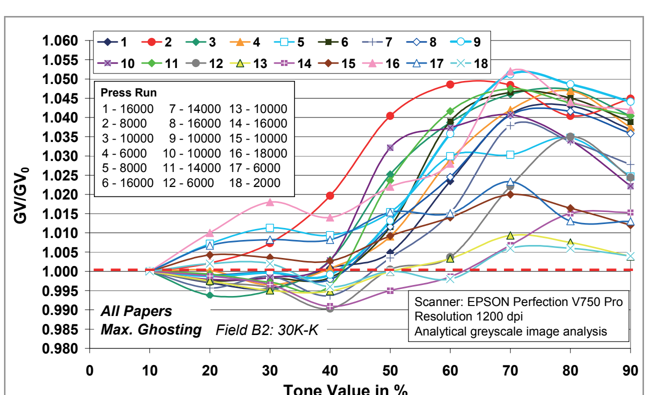


Figure 7: Equivalent circular diameter of printed dots

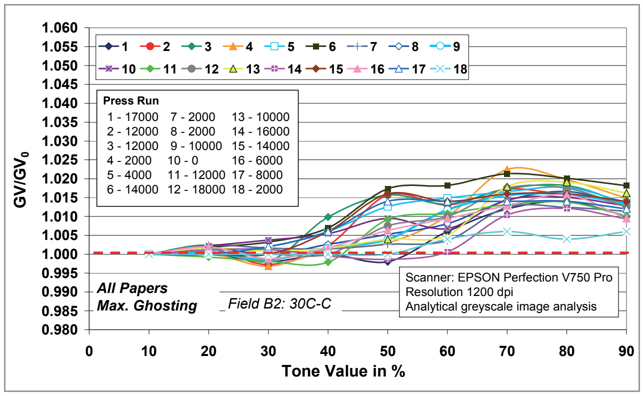
4.2.3 Direct and indirect ghosting

The ghosting effects described above may be the result of the action of the ink forces in one printing unit, and this is referred to as direct ghosting. This effect can, however, occur due to interactions in subsequent printing units and is then referred to as the indirect ghosting. Element B2 (Figure 5) contains fields for direct ghosting in the K printing unit (30K-K), in the C unit (30C-C), M unit (30M-M) and fields for indirect ghosting (30K-M und 30M-K).

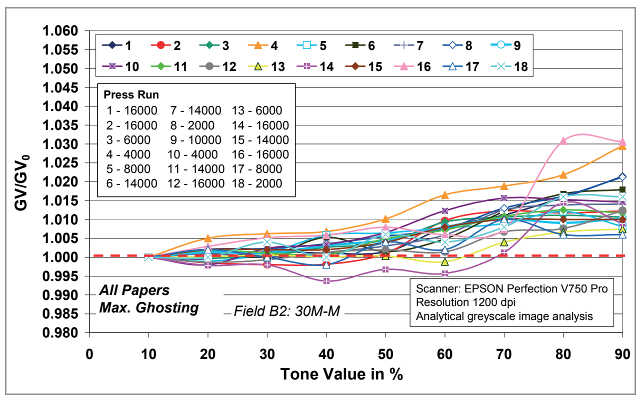
Figure 8 shows the grey value ratio GV/GV_0 for the cited color combinations for maximum ghosting that occurs on the paper at varying number of copies (rotations). Figure 8 also reveals that brightening due to ghosting occurs to the greatest extent in the first printing unit (K). In addition, an increase was observed in the GV/GV_0 ratio in C, followed by the M unit, although in a much weaker form than in the 30K-K field. It is noted that the paper also behaves differently. The equivalent circular diameter was evaluated via a specific threshold value in a color image, where a filter was used that was complementary to each respective color. In the color Y (yellow) ghosting could not be visually detected, so that these fields were excluded from the investigation. This is probably due to the fact that the ghosting effect appears strongly in the first printing unit and its strength decreases in the following ones. Additionally, the human eye, because of the lower contrast of color yellow (Y) to the paper is less sensitive to the effect than in the case, for example, of cyan.



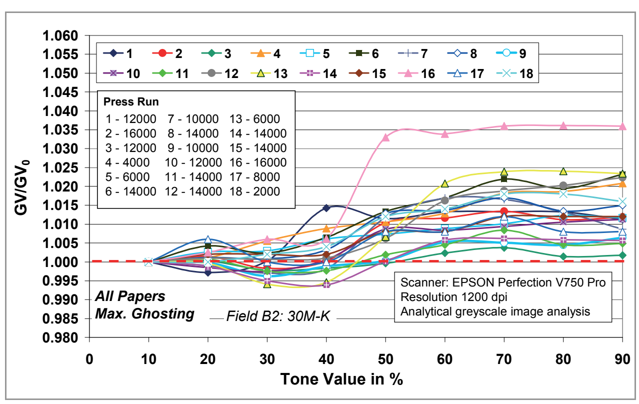
Direct ghosting in the K printing unit



Direct ghosting in the C printing unit



Direct ghosting in the M printing unit



Indirect ghosting - 30M-K field

Figure 8: Direct and indirect ghosting as a function of the tone value of the tile

Figure 9 compares the GV/GV_0 ratios for all papers with a tone tile value of 80 % on the non-ghosting side for direct and indirect ghosting combinations, the ghosting value of the paper being expressed by the paper identification number.

On the one hand, the ghosting range in the print combinations is obvious and, on the other hand, it is evident that the ranking of the ghosting effect for the papers is not uniform for these combinations. For instance, paper 3 (green dotted line) in 30K-K field shows very strong ghosting. In the print combinations 30C-C and 30M-M, however, the ghosting of this paper was in the mid-field of all the papers. Indirect ghosting (30M-K) was not able to be verified for paper P3. Although the ghosting effect is most prominent for most papers in the K-K field, this cannot be generalized as evidenced by paper P13. In this case, the maximum is even located in the M-K field and in the C-C field for direct ghosting. Even matte paper P16 clearly expresses this ghosting inconsistency in the print combinations. Atypical of matte papers, it exhibits high ghosting values in

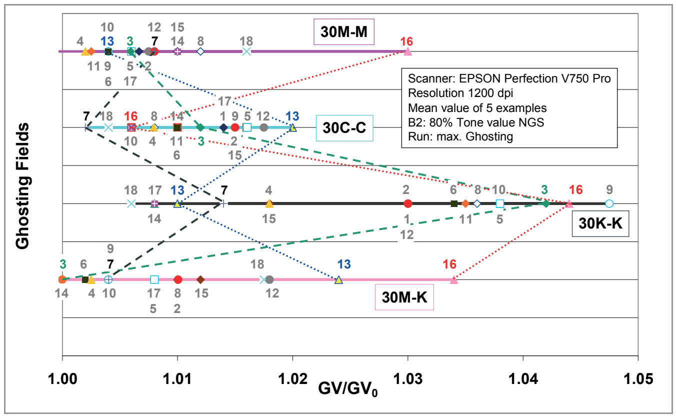


Figure 9: Ghosting tendency of papers studied - direct and indirect ghosting

all combinations except for 30C-C. It might be hastily concluded from this comparison that paper has no impact on ghosting, since ghosting would otherwise have to have virtually the same intensity in all print combinations and the result would be an unambiguous paper ranking for all combinations. The origins of these differences are probably due to the complexity of the printing process itself and in the dynamic behavior of ghosting itself. These questions must be investigated in greater detail in future.

4.2.4 *Ghosting tendency of the examined papers*

Based on the equivalent circular diameter (CED) ratio, the ghosting tendency of paper via the tone value of the tile on the non-ghosting side is illustrated using the 30K-K field as an example (where most papers exhibit a strong ghosting tendency). Unlike the ratio of the mean grey values of the tile region (GV/GV_0), however, values below 1.0 indicate ghosting; values above 1.0 indicate darkening.

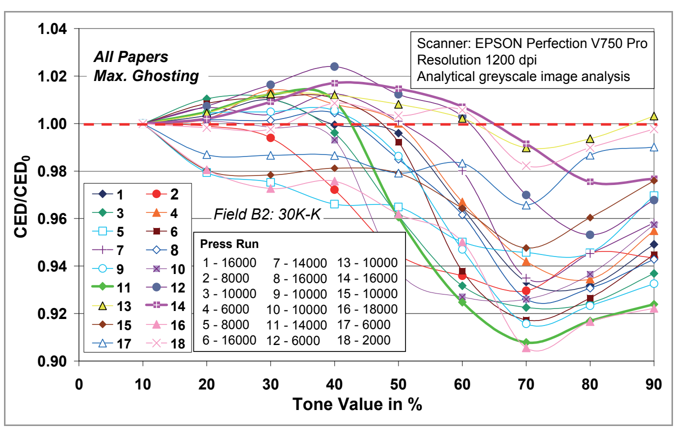


Figure 10: Ghosting tendency of papers studied - equivalent circular diameter ratio

It can be seen from Figure 10 that the studied papers show different behaviours regarding their ghosting tendency.

The basic differences in behaviour are compiled by way of example in Figure 11 and include form, beginning, gradient and intensity.

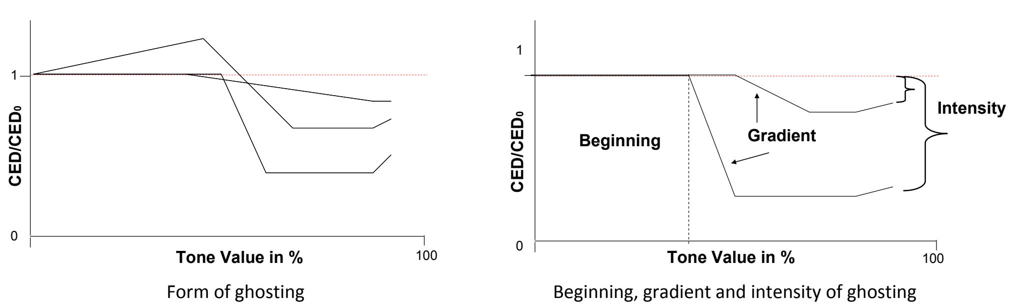


Figure 11: Ghosting parameters

Of these four parameters, intensity was given top priority since it is the only available variable for characterizing ghosting in practice. The other parameters are accessible only through the ghosting printing plate that was especially developed for this purpose. All four parameters were compiled both for direct (K-K, C-C, M-M) and indirect (M-K) ghosting in Table 2.

The data pertaining to the ghosting behavior shown in Table 2 is colour coded according to the ghosting tendencies regarding starting point, intensity and ghosting development trend. In addition, the number of impressions in which the maximum ghosting intensity was reached varied from one printing unit to another. It should be noted in this context that the paper passes through the printing units within a time frame of approx. 0.1 s and that the paper web was already dampened by the fountain solution after the first printing unit. A comprehensive evaluation of the data contained in Table 2 has not yet been completed. Initial considerations of possible relationships between ghosting tendency and basic paper properties are shown below by way of example for the field B2 30K-K which showed maximum ghosting intensity.

Table 2: Ghosting parameters for studied papers at maximum ghosting

	30K-K					30C-C				
P	Beg	Grad	Amp	Form	Run	Beg	Grad	Amp	Form	Run
1	60	0.032	0.075	Ghosting	16000	60	0.047	0.078	Darkening then ghosting	17000
2	40	0.022	0.067	Ghosting	8000	50	0.055	0.090	Ghosting	12000
3	50	0.035	0.088	Darkening then ghosting	10000	40	0.068	0.096	Ghosting	12000
4	60	0.033	0.074	Darkening then ghosting	6000	60	0.041	0.089	Ghosting	2000
5	60	0.024	0.043	Faint ghosting	8000	50	0.029	0.057	Ghosting	4000
6	60	0.054	0.092	Darkening then ghosting	16000	50	0.054	0.075	Ghosting	14000
7	60	0.021	0.070	Darkening then ghosting	14000	70	0.050	0.051	Darkening then ghosting	2000
8	60	0.023	0.075	Ghosting	16000	60	0.014	0.053	Faint ghosting	2000
9	60	0.039	0.089	Ghosting	10000	60	0.037	0.065	Darkening then ghosting	10000
10	50	0.055	0.074	Ghosting	10000	50	0.010	0.034	Faint ghosting	0
11	50	0.049	0.101	Darkening then ghosting	14000	50	0.064	0.084	Darkening then ghosting	12000
12	70	0.033	0.059	Darkening then ghosting	6000	60	0.033	0.061	Darkening then ghosting	18000
13	70	0.012	0.019	Faint ghosting	10000	70	0.064	0.071	Darkening then ghosting	10000
14	70	0.016	0.030	Darkening then ghosting	16000	70	0.057	0.045	Darkening then ghosting	16000
15	70	0.016	0.029	Faint ghosting	10000	50	0.050	0.061	Ghosting	14000
16	70	0.045	0.071	Ghosting	18000	50	0.019	0.056	Darkening then ghosting	6000
17	--	--	--	--	--	50	0.036	0.041	Faint ghosting	8000
18	70	0.023	0.016	Faint ghosting	2000	70	0.039	0.028	Darkening then ghosting	2000

	30M-M					30M-K				
P	Beg	Grad	Amp	Form	Run	Beg	Grad	Amp	Form	Run
1	60	0.016	0.065	Faint ghosting	16000	40	0.058	0.068	Ghosting	12000
2	60	0.017	0.039	Ghosting	16000	50	0.028	0.048	Ghosting	16000
3	60	0.016	0.039	Ghosting	6000	60	0.013	0.026	Faint ghosting	12000
4	--	--	--	--	--	60	0.007	0.038	Faint ghosting	4000
5	--	--	--	--	--	60	0.009	0.032	Faint ghosting	6000
6	70	0.016	0.050	Faint ghosting	14000	50	0.016	0.058	Faint ghosting	14000
7	70	0.019	0.041	Faint ghosting	14000	50	0.053	0.081	Ghosting	10000
8	70	0.016	0.054	Faint ghosting	2000	50	0.029	0.048	Ghosting	14000
9	--	--	--	--	--	50	0.006	0.022	Faint ghosting	10000
10	60	0.023	0.044	Ghosting	4000	50	0.030	0.044	Ghosting	12000
11	70	0.015	0.033	Ghosting	14000	60	0.011	0.035	Faint ghosting	14000
12	70	0.014	0.029	Faint ghosting	16000	60	0.030	0.058	Ghosting	14000
13	--	--	--	--	--	50	0.042	0.103	Darkening then ghosting	6000
14	80	0.052	0.056	Darkening then ghosting	16000	60	0.025	0.043	Darkening then ghosting	14000
15	--	--	--	--	--	--	--	--	--	--
16	80	0.075	0.080	Ghosting	16000	50	0.087	0.116	Ghosting	16000
17	--	--	--	--	--	--	--	--	--	--
18	70	0.018	0.037	Faint ghosting	2000	50	0.029	0.062	Ghosting	2000

Beg = SVx = First instance of ghosting
Grad = $CED/CED_0(SVx-10) - CED/CED_0(SVx)$
Amp = $1 - MaxCED/CED_0$
Run = Print run at MaxAmp

Form
= Ghosting
= Darkening then ghosting
= Faint ghosting

= Group 1 - intense
= Group 2 - less intense
= Group 3 - faint
= Group 4 - very faint
-- = No Ghosting

5. Paper analysis with a view to ghosting

5.1. General aspects

The analysis of the ghosting tendency of papers took the following paper properties into consideration:

- general properties (grammage, thickness, specific volume);
- strength properties (modulus of elasticity, bending stiffness);
- topography;
- wetability (surface tension);
- penetration;
- other properties (ink consumption, coating layer thickness distribution, base paper thickness).

In a first process step, statistical analysis was carried out with help of a statistical programme entitled CORNERSTONE (Wember, 2008) based on the available data for 18 printed papers. This analysis, however, did not produce any confident robust findings on the dependent relationship between the ghosting tendency of the papers and the basic paper properties mentioned above due to the low statistical accuracy, i.e. extremely high confidence intervals in some cases. To remedy the situation, the data was prepared for a case study in which the papers were divided into four groups based on their ghosting tendency (Table 3). Only the relevant paper properties obtained from the case study are presented in this chapter.

Table 3: Classification of papers into groups for case study based on ghosting intensity

Ranking - maximum Ghosting									
G	**Nr.**	**Run**	**GV/GV₀-1**	**1-CED/CED₀**	**G**	**Nr.**	**Run**	**GV/GV₀-1**	**1-CED/CED₀**
I	**3**	10,000	0.0522	0.088	III	**16**	18,000	0.0340	0.071
I	**9**	10,000	0.0507	0.089	III	**12**	6,000	0.0321	0.059
I	**6**	16,000	0.0479	0.092	III	**5**	8,000	0.0233	0.043
I	**11**	14,000	0.0473	0.101	IV	**15**	10,000	0.0143	0.029
I	**4**	6,000	0.0461	0.074	IV	**14**	16,000	0.0132	0.030
I	**1**	16,000	0.0457	0.075	IV	**13**	10,000	0.0121	0.019
II	**8**	16,000	0.0417	0.075	IV	**17**	6,000	0.0107	-
II	**2**	8,000	0.0397	0.067	IV	**18**	2,000	0.0040	0.016
II	**10**	10,000	0.0392	0.074					
II	**7**	14,000	0.0386	0.070					

G - group; maximum ghosting; GV/GV-1 - change of average grey value;
1-CED/CED₀ - change of equivalent circular diameter of printed dots

5.2 Bending stiffness

Preliminary statistical studies indicated that the ghosting tendency of the papers studied greatly depended on the bending stiffness or the thickness which figures into stiffness to the third power (observation of coated paper approximately as a homogenous bar - no parallel axis/Huygens-Steiner theorem). For this reason, the first step involved investigating bending stiffness in greater detail.

Figure 12 shows both dry and wet stiffness.

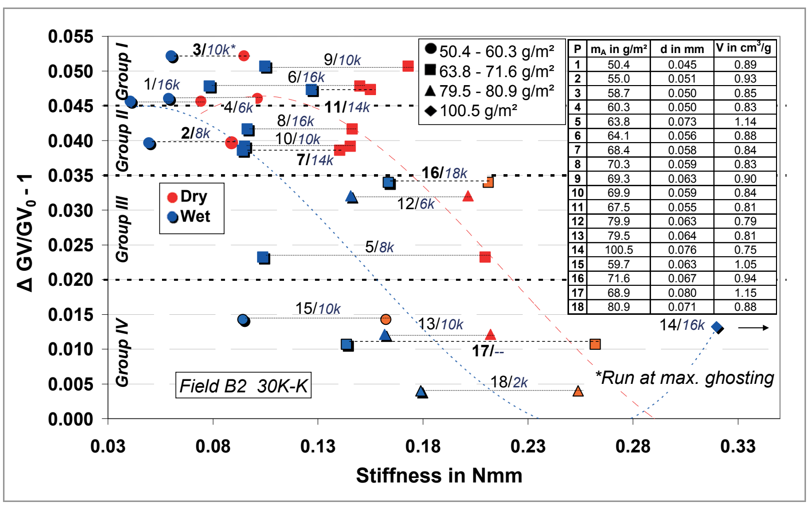


Figure 12: Ghosting tendency as a function of dry and wet stiffness of paper

The papers were usually analyzed under standardized conditions (T=23 °C, RH=50 %). These conditions, however, were not comparable to those in the printing process, where paper also comes into contact with a fountain solution and the water emulsified in the printing ink. Wet stiffness was also studied on a laboratory scale to better simulate conditions in the printing press. For this purpose, the paper strips for tensile strength testing were immersed in water for one second, the residual water was removed with blotting paper and after a drying phase lasting 30 s, the tensile strength was measured under standard conditions in a horizontal tensile tester. The wet stiffness was calculated from the wet modulus of elasticity obtained and the thickness of paper. The dry and wet stiffness are connected by a dashed line in Figure 12 above which the number of the paper is noted as well as the number of impressions during which maximum ghosting occurred. The different symbols in the diagram represent paper grammage ranges. The core finding from Figure 12 is that papers with low stiffness have a higher ghosting tendency.

It was also found, however, that the range of stiffness parameters within a ghosting group is quite large on the one hand and, on the other hand, that papers with identical or similar stiffness levels are allocated to different ghosting groups. Paper 3, for instance, belongs to ghosting group 1 (maximum ghosting), while paper 2 - despite its similar dry and wet stiffness - is allocated to group 2.

The cause of the difference in ghosting tendency will be investigated more closely in the following section using these two papers as examples.

5.3 Paper surface

5.3.1 Scanning electron microscope (SEM) visualizations

Figure 13 and Figure 14 show SEM photomicrographs of the surfaces of papers 2 and 3 at different magnifycations.

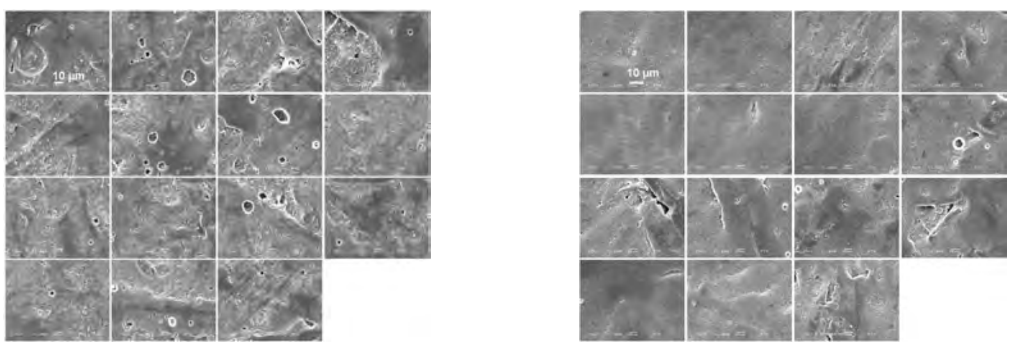
These serve to visualize the surface differences of both papers. The magnification of 1 000 x was chosen to provide an overview of the surface structure. This was accomplished by choosing 15 random locations in the paper, each image having an area of 128 μm x 96 μm. This corresponds to the size of the printed dots (scanner-based printed dot diameter at 30 % tone value amounts to approx. 75 μm - 85 μm).

Figure 13 demonstrates that both papers show surface defects (e.g. holes) which may have originated from air bubbles in the coating color. Furthermore, it is also evident that the coverage of the base paper is not uniform; rather a fibre-related surface defect was identified. A direct comparison of both papers clearly shows the greater evenness of the surface of paper 3. Images at 10 000 x magnification verify this statement.

Figure 13 also reveals that the surface of the paper 2 contains more and larger pores than the surface of paper 3.

Paper 2 ($\Delta GV = 0.0397$) **Paper 3 ($\Delta GV = 0.0522$)**

Ghosting side - Maximum ghosting in field 30K-K (direct ghosting)

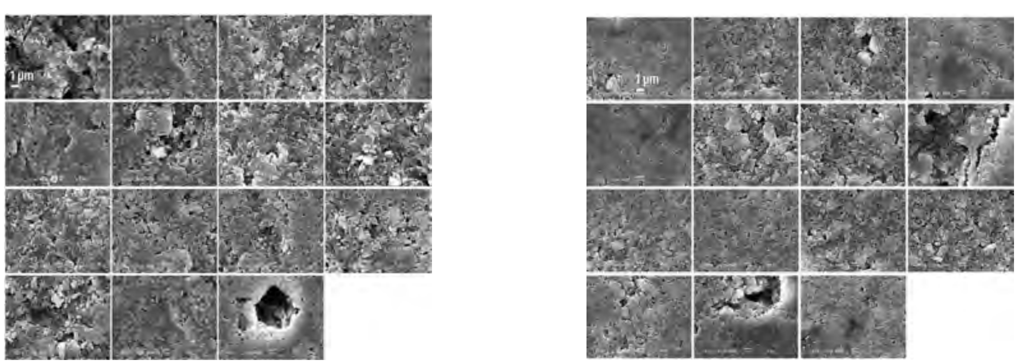


Magnification 1 000 x - single image size 128 μm x 96 μm; total image area 512 μm x 384 μm

Figure 13: Surface images of two papers with different ghosting tendency recorded by scanning electron microscope (SEM) at 1 000 x magnification

Paper 2 ($GV/GV_0 - 1 = 0.0397$) **Paper 3 ($GV/GV_0 - 1 = 0.0522$)**

Ghosting side - Maximum ghosting in field 30K-K (direct ghosting)



Magnification 10 000 x - single image size 13 μm x 10 μm; total image area51 μm x 38 μm

Figure 14: Surface images of two papers with different ghosting tendency recorded by scanning electron microscope (SEM) at 10 000 x magnification

In addition, 20 cross-sectional photomicrographs were prepared at a magnification of 700 x. Figure 15 shows the cross-sectional images of papers 2 and 3 and of papers 7 and 11, whose grammages are somewhat higher, however. One cross section of each paper is shown as examples. Unevenness of the coating layer coverage is obvious in all papers. As can be expected, however, the papers with 70 g m^{-2} show much less unevenness than the lighter papers. The relationship between ghosting tendency and the visualizations of paper structure in the z-direction is not obvious at first glance. These relationships, however, cannot be specified in more detail until the results of image analysis are available. These analyzes are currently being performed.

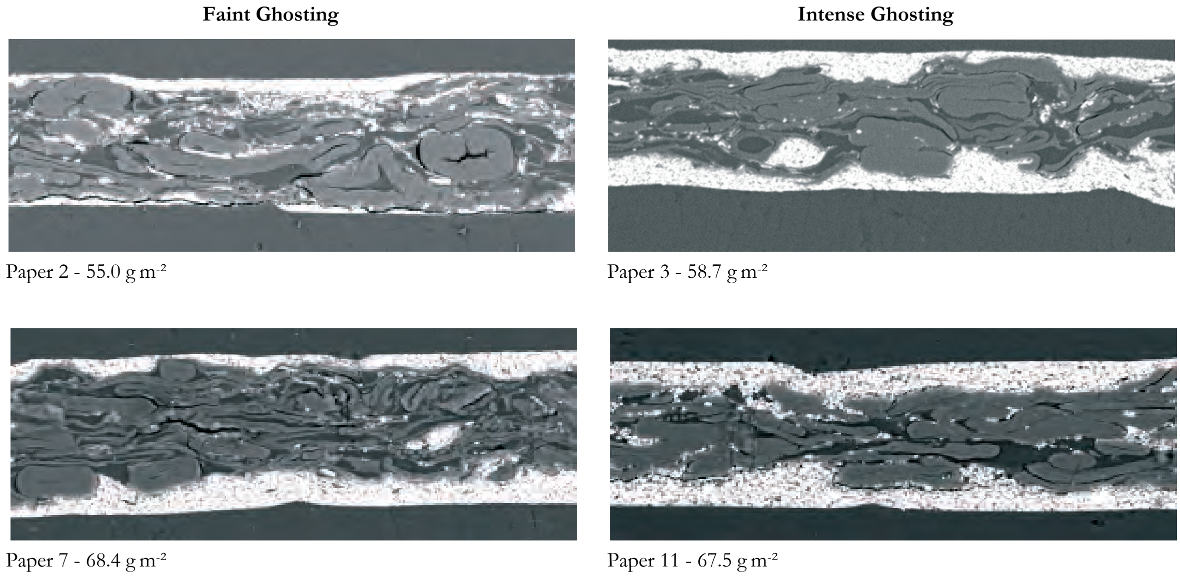


Figure 15: Cross-sectional images of four papers with different ghosting tendencies imaged by scanning electron microscope (SEM) at a magnification of 700 x

5.3.2 Topography

Whereas the SEM images in Figure 13 and Figure 14 permit visualization of the surface only, the 3D data sets produced by the principle of focus variation (Scherer et al., 2007; Klein et al., 2009), (IFM G3 - Alicona Imaging GmbH) provide not only visual information of the surface, but can also describe the surface quantitatively.

Figure 16 shows the surface images of papers 2 and 3 measured by focus variation with 20 x objective and filtered with a cut-off wave-length of 200 µm.

The surface of paper 2 (Sa = 0.72 µm) is substantially rougher than the surface of paper 3 (Sa = 0.44 µm), a fact confirmed by the four additional topographical parameters listed in Figure 16.

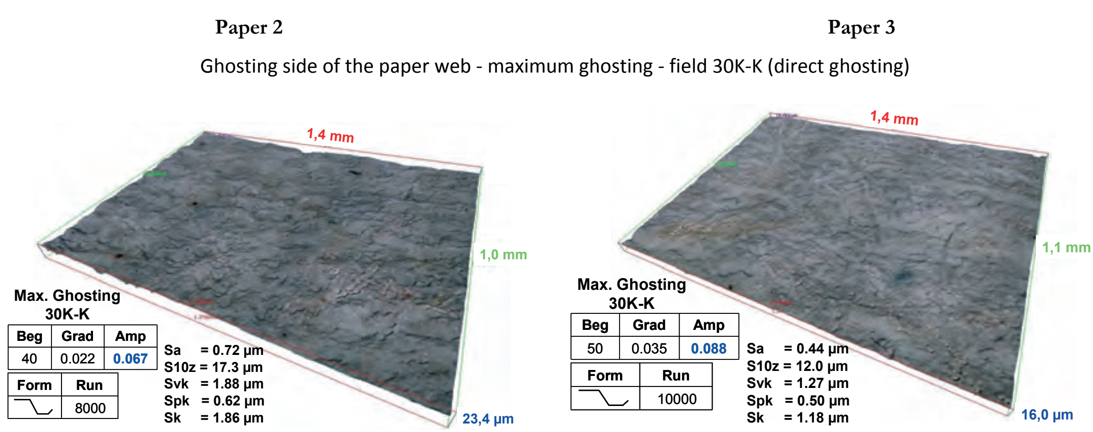


Figure16: 3D surface images of two papers with different ghosting tendencies

Using the statistical analysis mentioned above regarding the relationship between the tendency towards ghosting and basic paper properties, it was not possible to find any relationships or dependencies for the topographical parameters (a correlation coefficient of r = 31.5 % was found for the roughness average - Sa).

A graphical presentation of the data is contained in Figure 17. In this case, the roughness averages (Sa) were studied taking wet stiffness (4 groups) into account. If wet stiffness is included in the observation of surface roughness, it can be concluded that as roughness decreases, the ghosting tendency for papers rises. A few papers (P9, P11 and P13) deviate from this tendency.

The causes of this behavior have not yet been clarified in detail. It can be assumed that the causes lie in other paper-related interactions which have not yet been explored.

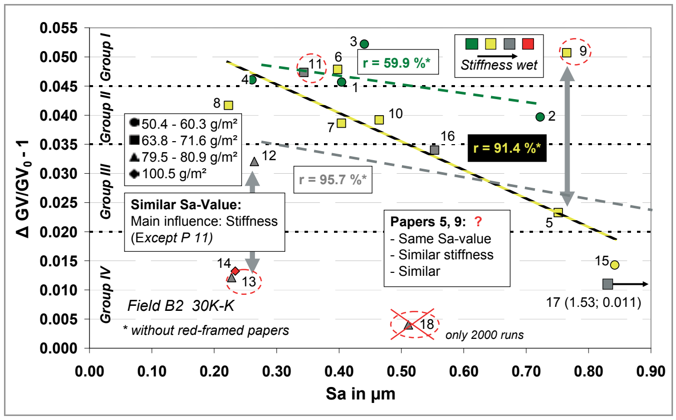


Figure 17: Ghosting tendency as a function of average roughness

5.4 Dynamic penetration

Two additional important paper properties that are mentioned in conjunction with paper printability are runnability and wetability of the paper surface (surface tension) and the penetration behavior of liquids like water and oil. The dynamic penetration behavior of papers with respect to water and n-heptane was determined with the emco DPM (emco, 2006) and the time point at which fibre absorption begins was used to compare papers.

Figure 18 presents in graphical form the dependence of this value for both water and n-heptane (emco6) with regard to stiffness, citing the ghosting tendency of the paper at the same time.

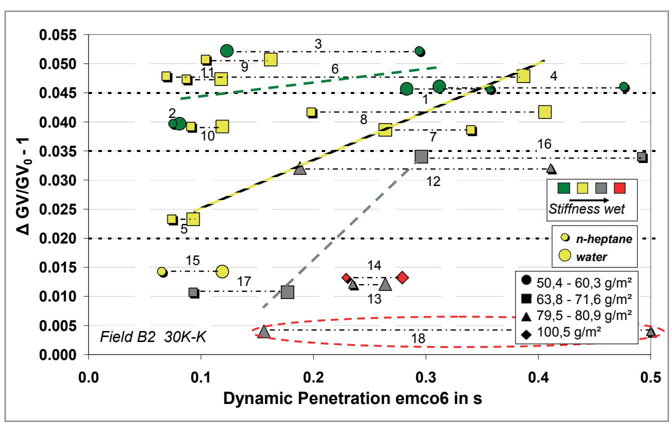


Figure 18: Ghosting tendency as a function of dynamic penetration

The emco data for water and n-heptane are connected by a dashed line and labeled with the number of respective paper similar to the illustration of dry and wet stiffness. Figure 18 reveals that the ghosting tendency of papers decreases the more rapidly the liquid penetrates. However, the difference in penetration behavior was extremely different within one ghosting group.

6. Summary and results

Mechanical ghosting in heatset web offset printing is a print-related phenomenon that manifests itself as an unintentional and unwanted partial brightening of the printed image on the ghosting side as a function of the motif on the opposite side of the paper. Ghosting is attributed to a reduction in dot size.

The resulting deterioration in print quality causes the amount of printer´s waste to increase or results in claims for compensation filed by dissatisfied customers. Ghosting is thus a considerable economic factor for print shops. The cause of ghosting must be seen in the interaction of paper, printing ink, printing press, print-related conditions, the paper itself not necessarily being the predominant factor in the equation. In order to be able to better evaluate the influence of paper, 18 paper grades were printed in an industrial-scale print trial on a four-color heatset printing press using a "ghosting form" especially developed for this purpose and subsequently subjected to a comprehensive analysis of both the printing and paper technologies involved.

Imaging analysis tools that allow the efficient measurement of several different performance characteristics were developed to evaluate the ghosting effect. Direct measurement of dot size is the most meaningful and representative way of evaluating ghosting. A very good correlation was able to be established between the analytical results and the visual evaluation of the ghosting effect. We were able to verify the correlation between ghosting and the number of print impressions. As far as the dependency between ghosting and the tone value of the motif on the non-ghosting side was concerned, differences were worked out regarding form, starting point, gradient and intensity of ghosting for the papers studied. Intensity was employed as the ghosting criterion in the initial correlation between ghosting and paper properties.

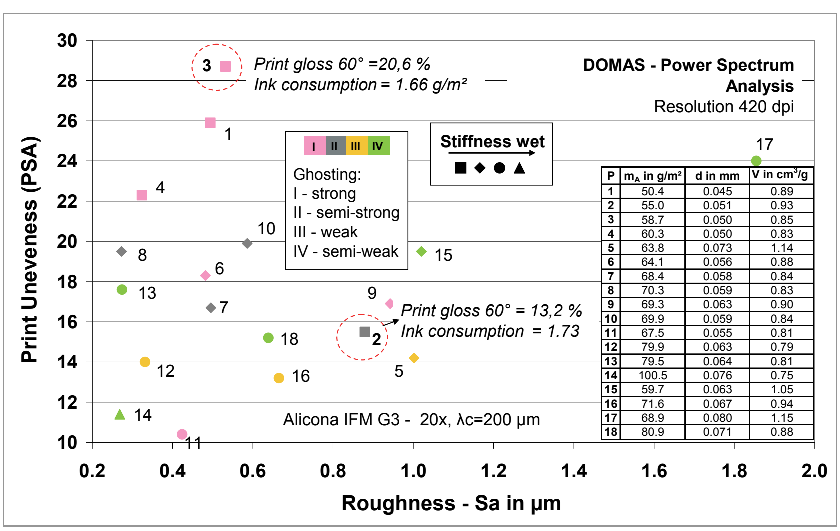
Statistical analysis of the data revealed that it will not be possible to correlate individual paper properties and the ghosting tendency of the paper to a single cause in view of the complexity of the overall process. As the number of samples was too small, it was not possible to identify paper-related interactions and their impact on ghosting based on statistical methods. The papers were therefore grouped based on their ghosting tendency and then subjected to a case study. Of the paper properties studied, wet and dry stiffness of the papers had the greatest impact on the manifestation of ghosting, i.e. increasing stiffness tends to decrease the ghosting tendency. Regarding surface topography, it could be demonstrated that the ghosting tendency declined as roughness increased. This trend is only obvious, however, if the effect of stiffness is taken into account, since stiffness is the more dominant factor. This applies as well to the penetration behavior of the paper with respect to water or oil, where a reduction in the ghosting tendency was found in conjunction with quick penetration after adjustment for stiffness.

The results presented in this work constitute preliminary evaluations of a considerable volume of data which is still being processed and evaluated. Especially issues concerning the impact of paper on direct and indirect ghosting as well as the influence on the starting point and form of ghosting have not yet been fully understood and will be studied in greater detail.

In addition, the complex dependencies with other properties which affect the print results, some of which are still not completely known, will be analyzed in greater depth.

Focusing solely on the ghosting tendency of paper, however, is not meaningful either, since the economy of the printing process and print results depend on many other factors. Figure 19 is intended to show this using print unevenness as an example.

Figure 19 demonstrates that print unevenness in a halftone area (20C, 20M, 20Y, 20K) on the non-ghosting side has a wide bandwidth and is linked to ghosting and roughness, but not as the sole influencing factors. This known fact is verified by the fact that ink consumption rises and print gloss drops with increasing roughness (refer to papers 2 and 3).



P	m_A in g/m²	d in mm	V in cm³/g
1	50.4	0.045	0.89
2	55.0	0.051	0.93
3	58.7	0.050	0.85
4	60.3	0.050	0.83
5	63.8	0.073	1.14
6	64.1	0.056	0.88
7	68.4	0.058	0.84
8	70.3	0.059	0.83
9	69.3	0.063	0.90
10	69.9	0.059	0.84
11	67.5	0.055	0.81
12	79.9	0.063	0.79
13	79.5	0.064	0.81
14	100.5	0.076	0.75
15	59.7	0.063	1.05
16	71.6	0.067	0.94
17	68.9	0.080	1.15
18	80.9	0.071	0.88

Figure 19: Print unevenness as a function of roughness taking stiffness and ghosting tendency into account

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Process parameters in flexography: effect on UV ink transfer and image quality characteristics

David Bould[1], *Timothy C. Claypole*[1], *David Galton*[2]

[1] University of Wales, Swansea, UK E-mails: d.c.bould@swansea.ac.uk; t.c.claypole@swansea.ac.uk
[2] Asahi Photoproducts Ltd, Shenfield, UK E-mail: dg@asahi-photoproducts.co.uk

Abstract

An investigation has been performed, whose objectives were to quantify the combined effects of process parameters on UV ink transfer and print quality in flexographic printing. This paper reports the analysis of key factors identified in a factorial designed experiment that builds on previous research into the flexographic printing process. The experiment, in the form of a press trial was performed on an uncoated paper substrate, to assess the effects of speed, plate to substrate engagement, anilox to plate pressure and ink viscosity on image reproduction. Solid density, tone gain and dot circularity were used to assess the extent to which each parameter alters the printed image. Although process parameters, such as dot circularity has been extensively researched previously, these investigations were mainly performed for the offset lithographic printing process. A search of the literature also showed that the research that has been performed into process parameters using flexographic printing, focuses primarily on polymeric or coated paper substrates, where the immobilisation of ink into the substrate is low.

As a result of the investigation, it was concluded that plate to substrate engagement had the greatest effect of all the parameters considered, as it affected all measured properties. Anilox to plate pressure was shown to affect tone gain in the midtone and shadow regions. Speed was observed to have no effect on solid density or dot circularity. It did, however, affect the highlight halftone dots, although no effect was observed for either the midtones or shadow regions. Ink viscosity had negligible effect when considered as a single parameter, but interacted with plate to substrate engagement to have an effect on tone gain in the midtones.

Keywords: flexography, UV ink, circularity

1. Introduction and previous literature

Control the ink transfer from the anilox roll to the printing plate and then from the plate to the substrate are key parameters in the flexographic process and consistent image reproduction relies on understanding the response of the press, in terms of the ink transfer, to changes in press parameter settings. A schematic of the flexographic printing process is shown in Figure 1.

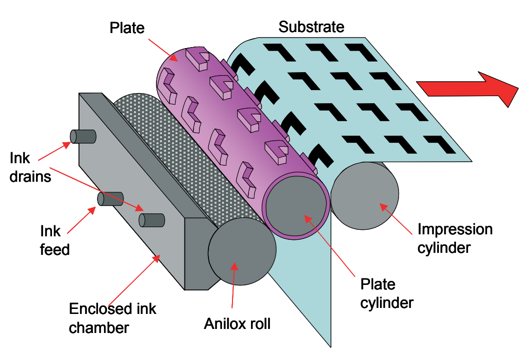

Figure 1: Schematic of flexographic printing process

During a single print cycle, ink is supplied from an engraved anilox roll, to the raised regions of a photopolymer printing plate, under a small pressure. The ink is then transferred to a substrate at the plate/impression cylinder nip, again under pressure.

Little previous research exists to evaluate the impact of different process variables in flexography. Previous studies into letterpress (Fetsko and Walker, 1955; De Grâce and Mangin, 1983, 1987) have examined process parameters, including effects of ink film thickness, printing speed and printing pressure. As a result of these investigations, it was determined that ink transfer is a result of a combination of ink film splitting at the nip exit and immobilisation of ink in a porous substrate (Fetsko and Walker, 1955). As press speed increased, the film split point was shown to move towards the substrate, resulting in decreased ink transfer from the plate (DeGrâce and Mangin, 1983, 1987). Furthermore increasing print pressure did not affect film splitting, but did increase ink immobilisation into porous substrates. As these investigations were performed using letterpress technology, which used a rigid image carrier, it is not clear whether the same trends are evident for flexographic printing, where deformation of the image carrier can have a large effect on the quality of the resultant print (Bould et al., 2004a, 2004b, 2004c). Therefore effects of process parameters, such as printing speed and printing pressure, need to be studied further, using the flexographic printing process.

The influence of ink viscosity, anilox cell specifications and printing speed on optical density and tone gain were studied by Damroth et al. (1996). A production press was used to print UV inks with different viscosities onto a polyester substrate. The ink density was also reduced when the press speed was increased. However, this density reduction was less for higher anilox line rulings than for the lower anilox line rulings, where greater differences in density were observed. The tone gain was reduced as the anilox cell volume was increased. The tone gain was also less for higher anilox line rulings with the same cell volume. As a result of the investigation, the behaviour of UV curing inks, which do not shrink on curing, was characterised. The interaction between anilox line ruling and image line ruling was not explored. Furthermore, whilst the investigation focused on the ability to print highlights and shadows, the work does not explain how process parameters affect midtone halftone dots.

Bohan et al. (2003) examined the influence of contact pressures within a flexographic printing press on the solid density and tonal reproduction, using a clay-coated paper substrate and water-based ink. Increasing the engagement between the anilox and the ink chamber had the largest effect on the ink density. This was attributed to the deflection of the doctoring blades, which would reduce the effectiveness of the wiping action across the anilox roll therefore allowing more ink to transfer to the plate. Increasing the pressure between the anilox and the plate produced a small reduction in solid density, while the difference in solid density was negligible as the pressure between the plate and impresssion cylinder was changed. This was in direct contrast to the effect on tone gain, where the pressure between the plate and the impression cylinder was the dominant factor. This was attributed to deformation of the halftone dots on the printing plate (Bould et al., 2004a, 2004b, 2004c) and the penetration of the ink into the substrate (Ahmed et al., 1997; Bohan et al., 2000). The results also showed the other pressures had little effect on the tonal re-production. This research showed that the immobilisation of ink into a porous substrate is not the dominant parameter in ink transfer in the flexographic printing process. In addition, once the pores in the paper have received ink, there is little further penetration of ink into the paper, shown by the negligible effect of impression pressure on solid density.

Bould et al. (2004a) used finite element modelling to examine the deformation of dots on a flexographic printing plate when subjected to loadings similar to a printing nip. Two mechanisms of deformation were identified, expansion of the dot surface and barrelling of the shoulders. Increasing the nip engagement load between the plate and impression cylinder increased the dot areas on the plate due to these deformation mechanisms. The finer dots were more influenced by the nip pressure, with their rate of growth increasing with every pressure increment evaluated. The effect of dot area and line ruling on the plate were evaluated in an experimental printing trial using UV ink and a non-porous substrate Bould et al. (2004b). Increasing the nip pressure had a large effect on the printed dot area. This was particularly evident at low pressures. As the pressure was increased their rate of growth decreased, this was thought to be due to the finite amount of ink on the plate which limited how much the ink could spread on the substrate under the pressure of the nip contact. The rate of growth was also high for higher line rulings. The modelling results were combined with those of the printing trial Bould et al. (2004c) therefore quantifying the contribution of plate deformation to the printed physical dot area. Spreading of the ink within the nip contact accounted for the majority of the printed tone gain.

Fouche and Blayo (2001) examined the ink transfer from the printing plate for UV flexographic inks with different apparent viscosities and surface tensions onto a coated paper. Printing experiments were performed on two laboratory printability testers with corresponding tests carried out on a flexographic production press. An interaction was found between the ink film thickness on the plate and press speed. At high ink film thickness, there was no significant change in the optical density or gloss as the speed was changed. However, at low ink levels density increased with speed for high viscosity inks, but remained constant as speed increased for low viscosity inks. No explanation was presented for this result and does not agree with the results published by Damroth et al (1996), where density decreased as viscosity increased, for all ink levels.

A study of the literature has shown that there is little research into ink transfer in flexographic printing. Although some previous studies have been conducted, using letterpress technology, which was the pre-cursor to flexography, this involved ink transfer from a rigid image carrier to the substrate, backed by a compliant roller.

Therefore, these investigations did not consider how deformation of a photopolymer image carrier, such as those used in flexography, will affect ink transfer and its subsequent effect on image quality.

Other investigation, which have involved the flexographic process have focused on exploring effects of individual parameters. Therefore the objective of this investigation is to quantify the combined effects of process parameters on ink transfer and print quality, in flexographic printing. This will further the understanding of flexography, with particular regard to the effect of plate coverage on ink transfer.

2. Methodology

The trial was performed on a Timsons T-Flex 508 narrow web flexographic printing press, capable of a maximum speed of 260 m min^{-1}. A two level half-fractional factorial experiment was designed to examine the effects of anilox to plate pressure, plate to substrate engagement, printing speed and ink viscosity, on solid density, tone gain and colour gamut. A description of fraction factorial design and the methods used to analyse and interpret the results has been published by Box et al. (1978). Use of experimental design enabled the statistical significance of the changes in parameters to be quantified, as well as the effects of parameter changes to each quantified output (e.g. solid density) and the de-termination of any interactions between parameters. Although a four colour image was used, parameter changes were limited to the magenta print unit only, with the exception of the change in speed, which affected all colours.

The test image comprised solid and halftone patches for each colour, as well as a series of photographic renditions. The plates were Asahi DSH photopolymer plates, with a thickness of 1.70 mm and a Shore Hardness of 69 ° Shore A. The plates were mounted using 3M E1015 Cushion Mount tape. A 100 g m^{-2}, uncoated paper substrate was used for the trials, to enable ink transfer by both ink film splitting at the plate/substrate nip and also by ink immobilisation into pores of the substrate.

Ink was supplied to the anilox rolls via a chambered doctoring system, which allowed the ink to be recirculated between the sump and the enclosed chamber. In order that the volume of ink on the substrate was representative of the volume transferred during the printing process, a UV curing ink was used for the trial, which has minimal shrinkage of the ink film during the curing process, due to the crosspolymerisation of oligomer chains within the ink film as the ink is exposed to UV radiation. Free radical polymerising inks, supplied by Xsys, were used, as cationic inks, the alternative system for UV curing flexographic inks, would react with the surface of the paper substrate, resulting in the ink film not curing fully. Viscosity of the inks was characterised using a Zahn 4 efflux cup. This allowed the time, in seconds, to be recorded for a stream of ink, flowing from a hole in the bottom of an initially full cup of ink, to become discontinuous.

The details of the anilox rolls used during the investigation are shown in Table 1.

Table 1: Anilox roll specifications

	Cyan	Magenta	Yellow	Black
Screen ruling (cells/inch)	850	800	800	700
Anilox volume (cm^3m^{-2})	2.4	3.8	3.0	3.5

The press was configured such that the plate cylinder remained in a fixed position, and the anilox roll and impression cylinder were both moved relative to the plate. This enabled both the anilox to plate pressure and the plate to substrate pressure to be controlled independently of each other. Plate to substrate engagement was controlled by a calibrated gauge on the press, marked off in 25 µm increments. Although no gauge was available for the anilox to plate engagement, this was controlled through use of thin film load sensors, which were fed through the anilox to plate nip, whilst recording the nip force through data logging equipment. Speed was monitored via an induction gauge, mounted on a gear. This recorded the time interval between gear teeth passing the induction gauge. The signal was then processed and converted to give the press speed. The viscosity of the magenta was adjusted by adding 5 % UV reducer. Although this had the effect of causing a small reduction in ink pigment concentration, the effect was considered small in comparison with the large change in viscosity, which reduced from 132 s, to 58 s, Zahn 4 (Table 2).

Table 2: Parameter settings for press trial

	Setting 1	Setting 2
Anilox to plate pressure (N)	38	70
Plate to substrate engagement (µm)	75	125
Speed (m min^{-1})	18	67
Ink Viscosity (seconds, Zahn 4)	58	132

The settings used for the experiment are summarised in Table 2 and the experimental parameter settings, based on the half-fraction factorial design are presented in Table 3, where a level of *-1* represents Setting 1 and *+1* represents Setting 2.

Following completion of the experimental print trial, samples for each setting were analysed for the magenta solid density, tone gain and dot circularity. Solid density and 10 %, 40 % and 80 % tone gain were quantified using a GretagMacbeth Spectrolino Spectrophotometer. Dot

Table 3: Parameter settings for half- fraction factorial experiment

Experiment no.	Speed	Anilox/Plate pressure	Plate/Substrate engagement	Ink Viscosity
1	-1	-1	-1	-1
2	+1	-1	-1	+1
3	-1	+1	-1	+1
4	+1	+1	-1	-1
5	-1	-1	+1	+1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	+1

circularity was also determined for the 40 % coverages, by scanning the magenta halftone patches onto a computer, using a high resolution commercially available desk-top scanner and processed using Verity IA software. Circularity was defined as the ratio between the dot perimeter squared, and the dot diameter, equation 1.

$$Circularity = \frac{(Perimeter)^2}{Area} \quad [1]$$

Thus, a perfectly round dot would have a circularity value of 4π. Four samples were measured for each experiment. This corresponds to the number of samples required to account for the natural cyclic variation of the press, which had previously been established, (Bould, 2001). Analysis of the experiment was achieved by comparing the average response of each parameter at its low and high level setting, for each of the measured outputs (density, dot circularity and tone gain) (Montgomery, 1997). The range of the response for each parameter was compared to the standard deviation of the overall print trial, in order to determine whether or not the parameter was statistically significant. To obtain the standard deviation, the range of samples measured for each experiment was averaged. The four samples were averaged for each experiment and the standard deviation estimated, using equation 2, where R is the average range from the individual experiments and d_2 is Hartley's constant (Smith, 1991). The range of the response for each parameter was then compared to the standard deviation, and if the range of the response was greater than two standard deviations, the parameter was deemed to be significant.

$$s = \frac{R}{d_2} \quad [2]$$

Interactions between pairs of parameters was quantified by examining the effect of one parameter for both the low and high level settings of the second parameter, for each of the measured outputs. The interaction was deemed to be statistically significant if the change in response of one parameter, as the second parameter was varied, was greater than two standard deviations.

3. Results

3.1 Solid density

Results from the analysis of the half factorial array showed that only the plate to substrate engagement was a statistically significant parameter for the solid density. As the engagement increased, the density increased by 0.085 (Figure 2). As the investigation was conducted using a porous substrate, the density increased by greater penetration into the substrate as the engagement increased, as printing pressure has previously been shown to have no effect on the ink transfer by film splitting at the nip exit (DeGrâce and Mangin, 1983). There were no significant interactions observed between any of the parameters for solid density.

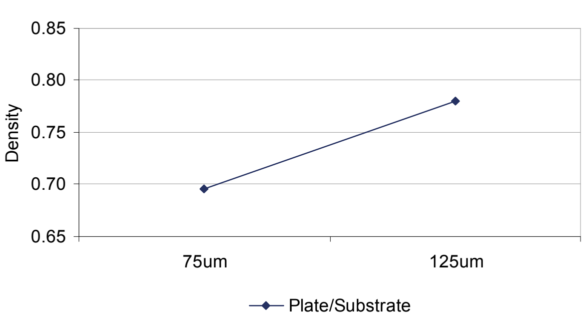

Figure 2: Effect of plat e to substrate engagement on solid density

3.2 Dot circularity

Plate to substrate engagement was shown to be the only significant parameter, which had an effect on dot circularity (Figure 3). In addition, no interactions between parameters were observed. As engagement increased from 75 μm to 125 μm, there was deterioration in the dot circularity. This was attributed to the greater squeeze on the ink film at the higher engagement and, due to the rolling nature of the contact between printing plate and substrate, and therefore resulted in increased tendency for asymmetrical spreading of the dots. The effects of plate to substrate engagement on dot circularity are in agreement with those obtained by Beynon (2007).

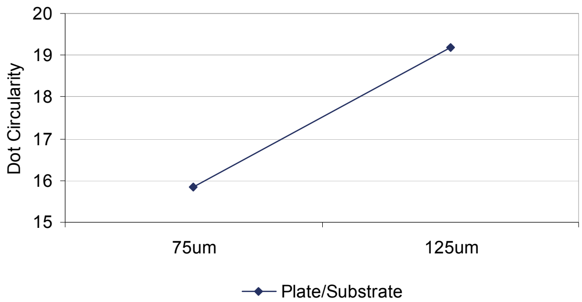

Figure 3: Effect of plate to substrate engagement on dot circularity

3.3 10 % tone gain

Analysis of the 10 % tone gain showed that speed and plate to substrate engagement were significant parameters. A graph showing the effect of speed on the 10 % tone gain is shown in Figure 4 and a graph showing the effect of plate to substrate engagement on the 10 % tone gain is shown in Figure 5.

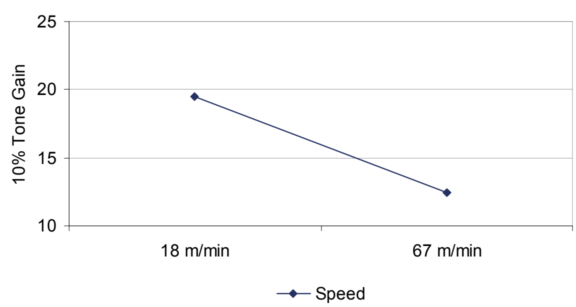

Figure 4: Effect of speed on 10 % tone gain

As speed was increased, the 10 % tone gain decreased, from 19.5 % to 12.4 %. As speed was shown to have negligible effect on solid density, the effect of speed on the 10 % tonal patch cannot be attributed to a change in ink transfer and must therefore be a result of reduced dot area on the substrate. This was attributed to reduced nip duration at the higher speed, resulting in less time available for ink spreading, due to the lateral squeeze of the ink film.

The change in tone gain as plate to substrate engagement increases (Figure 5) is consistent with the increase

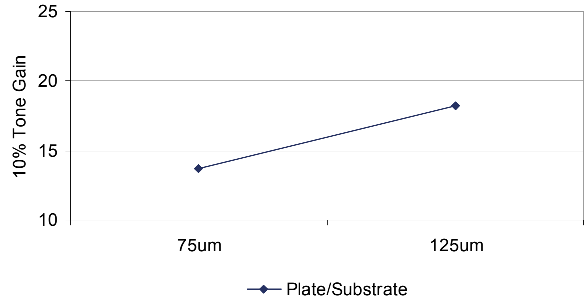

Figure 5: Effect of plate to substrate engagement on 10 % tone gain

in solid density (Figure 2), which was attributed to an increase in ink transfer. However, as the tone gain was calculated according to the Murray-Davies equation, the change in tone gain must be due to more than an increase in ink transfer alone and therefore the change observed for the 10 % coverage points to an increase in area of the 10 % halftone dots.

This was attributed to greater squeeze on the ink film as the pressure increased, forcing lateral spreading of the ink on the substrate. However the ability of the 10 % dots to gain in size was limited by the volume of ink present on the plate, due to the small area to perimeter ratio of the halftone dots. This is argument is developped further in section 0. No significant interactions occurred for the 10 % tone gain analysis.

3.4 40 % tone gain

Anilox to plate pressure and plate to substrate engagement were both shown to have an effect on tone gain in the midtone region. As anilox to plate pressure increased, the 40 % tone gain decreased. Previous research into ink release from the anilox roll to the printing plate in flexography (Cherry, 2007) has shown that increasing the pressure between the anilox and the plate can have a detrimental effect on ink release. The research showed that at higher anilox to plate pressures, solid density and dot area increased, but the volume of ink transferred for the halftone dots decreased. This was attributed to the differing mechanisms of plate deformation into the cells between the solid and the halftone patches, due to the presence of a shoulder on the halftone dots, which is not present for the solid. The decrease in 40 % tone gain observed in the current investigation can therefore be attributed to a reduction in ink transfer from the anilox cells onto the halftone dot on the plate and is in agreement with the results obtained by Cherry (2007).

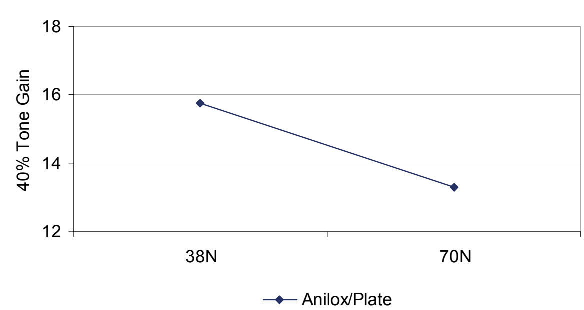

Figure 6: Effect of anilox to plate pressure on 40 % tone gain

The reasons for the change in tone gain with plate to substrate engagement are the same as those described in section 3.3. However, due to a greater volume of ink present on the halftone dots at the higher coverage, ink spreading was not limited by the quantity of ink on the halftone dots and therefore, the change in 40 % tone gain due to increased plate to substrate engagement was larger than the change observed for the 10 % coverage.

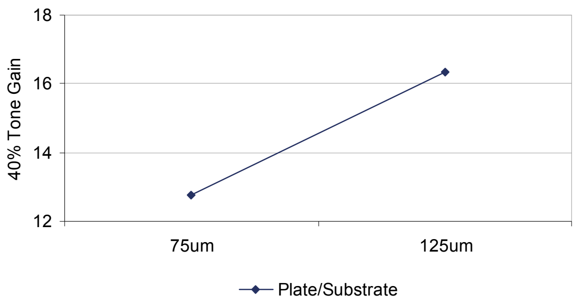

Figure 7: Effect of plate to substrate engagement on 40 % tone gain

Interactions were observed for the 40 % tone gain, between speed and anilox to plate pressure, and also between plate to substrate engagement and ink viscosity. The interaction between speed and anilox to plate pressure showed negligible effect of speed at the 38N pressure (Figure 8). However, at the 70N pressure, there was a decrease in the 40 % tone gain as the press speed increased. The effect of anilox to plate pressure when considered as a single parameter (Figure 6) showed that ink transfer from the anilox cells deteriorated as the pressure increased. The results for the speed/anilox to plate interaction show that this reduction in ink transfer is worse at high press speeds. The lower ink removal from the cells, due to the higher anilox to plate pressures, combines with the reduced nip duration at the higher speeds, to result in poorer deposit of ink on the 40 % halftone dots.

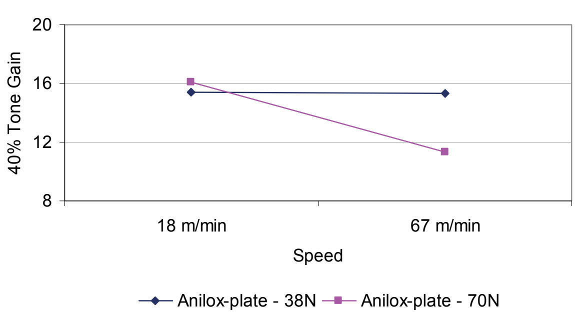

Figure 8: Interaction between speed and anilox to plate pressure on 40 % tone gain

The interaction between plate to substrate engagement and ink viscosity showed that at low viscosities, 40 % tone gain increased as the nip engagement increased. However, this trend was reversed for high ink viscosities, with tone gain decreasing as engagement increased. This was attributed to the ink's ability to spread on a porous substrate. At low viscosities, lateral spreading on the substrate is easier than at higher viscosities, which results in greater tone gain as engagement increases. For the high viscosity inks, the rate of ink spreading is reduced and so there is less opportunity for the ink to spread on the substrate whist within the printing nip.

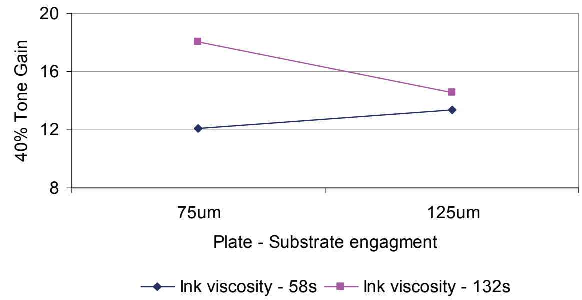

Figure 9: Interaction between plate to substrate engagement and ink viscosity on 40 % tone gain

3.5 80 % tone gain

Analysis of the 80 % tone gain data showed that anilox to plate pressure and plate to substrate engagement were both significant parameters. As anilox to plate pressure increased from 38N to 70N, the tone gain decreesed (Figure 10). This is consistent with the results for the 40 % tone gain and in agreement with the findings of Cherry (2007).

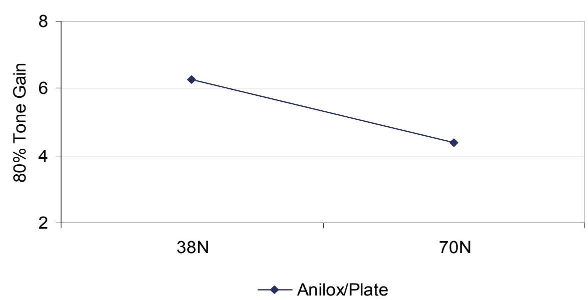

Figure 10: Effect of anilox to plate pressure on 80 % tone gain

The increase in 80 % tone gain as plate to substrate engagement increased is consistent with the results for both the 1 % and 4 % halftone patches. However, the 80 % coverage consisted of a solid area with holes to form the non-image regions, rather than discrete dots, as had been observed for the 1 % and 4 % patches. Therefore, although the volume of ink on the plate was higher than for the smaller coverages, tone gain was limited by the perimeter of the non-image holes, which decreased further as tone gain increased. This is described further in section 4.

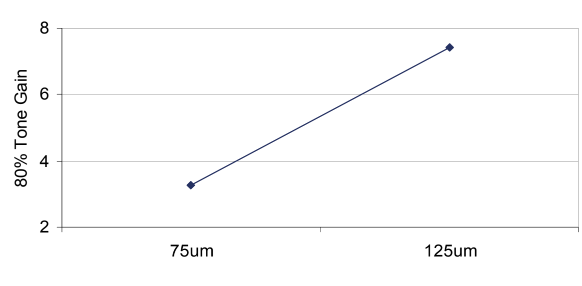

Figure 11: Effect of plate to substrate engagement on 80 % tone gain

4. Discussion

Plate to substrate engagement has been shown to affect all quality attributes during flexographic printing to a porous substrate. This is in agreement with the previous investigations into ink transfer performed using the letterpress process (Fetsko and Walker, 1955; DeGrâce and Mangin, 1983, 1987). These showed that plate to substrate engagement alters the ink penetration into the substrate, thus increasing solid density. Results from the investigation by Bohan et al. (2003), showed little effect of plate to substrate engagement, which they attributed to the pores in the substrate quickly filling with ink and then not accepting further quantities of ink as engagement increased. However, Bohan et al. used a coated substrate, which will allow less ink to penetrate into the substrate than the uncoated substrate used in the current investigation.

Effects of plate to substrate engagement on tone gain observed during the current investigation were attributed to ink film squeeze on the substrate surface and are consistent with previous investigations performed on non-porous filmic substrates (Bould et al., 2004b). The investigation has also shown that the effect of plate to substrate engagement is affected by percentage coverage of the halftone dots. For low coverages (e.g. 10 % coverage), the perimeter of the dot is large in comparison to the low volume of ink present. Therefore, as the plate to substrate engagement increases, the ability of the ink to spread is restricted by the quantity of ink. Tone gain is driven by dot perimeter and limited by ink volume. In the midtones (e.g. 40 % coverage), a larger volume of ink is present, as volume is proportional to the cube of the diameter. Therefore the volume of ink available to spread becomes of greater significance as plate to substrate engagement increases and changes in tone gain are driven by both dot perimeter and ink volume. In the shadow region (e.g. 80 % coverage), the dots join together to form a continuous surface, with the non-image regions formed by 'holes'. For these high coverages, there is a large volume of ink available for spreading, but the perimeters of the holes are relatively small, so changes in tone gain as plate to substrate engagement increases are driven by the ink volume, but limited by the available perimeter for spreading to occur.

A summary of the three cases for highlights, midtones and shadows is shown in Figure 12.

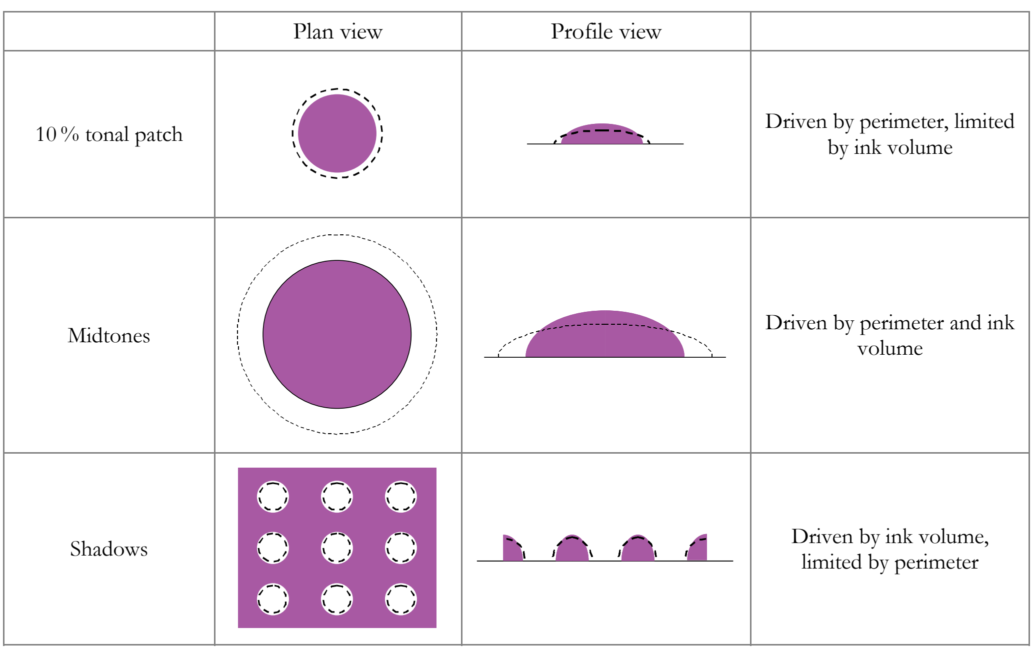

Figure 12: Effect of coverage on tone gain

Anilox to plate pressure has been shown to affect tone gain. However, no effect was observed for the highlight dot coverage (10 % coverage). That there was an effect for the larger dot sizes, but not for the 10 % coverage can be attributed to the small plate area of the 10 % dots, which were not able to carry sufficient ink for any effect of anilox to plate pressure to be observed.

Speed was only shown to affect the 10 % tone gain. As speed increased, tone gain decreased, which can be attributed to a shorter nip duration at higher speeds which reduced the ability of the ink to spread. That no effect of speed was observed at higher coverages, can be attributed to the larger volume of ink on the dots, which allows the ink to spread more easily and reduces the effect of the shorter amount of time available for film squeezing.

An objective of the investigation was to quantify the effects of flexographic process parameters, to compare the results, obtained using a deformable image carrier, with those previously obtained from letterpress investigations, where a rigid image carrier was used. The current investigation has shown that deformation of the plate against the anilox roll produces different trends for the solid density, and tone gain. Although anilox to plate pressure was not shown to be significant for solid density or 10 % tone gain, ink transfer from the anilox to larger halftone dots was affected by the nip pressure. This was attributed to the different deformation mechanisms of the plate against the anilox for solids and half-tones.

However, apart from the deformation of the flexographic plate against the anilox, the other trends observed during the current investigation are consistent with the previous research using letterpress technology. Therefore, although the deformation of the plate against the substrate does have a large effect on the quality of image reproduction, results obtained using a letterpress printing can be used to further the understanding of the flexographic printing process.

5. Conclusions

This investigation has improved understanding of the flexographic printing process. The effects of press speed, anilox to plate pressure, plate to substrate engagement and ink viscosity have been quantified using experimental design techniques, to allow effects of individual parameters and interactions between two parameters, to be quantified. The differences between the three halftone patches considered as well as the analysis of solid density has highlighted the limitations of press control using only a measure of solid density. This is because as the changes in tone gain, as press parameters were altered have varied between the highlight, midtone and shadow patches, which have also been shown to be different to the results for solid density.

Therefore any process control should also include a fuller analysis of the entire tonal range. As a result of the investigation, the following conclusions have been drawn:

- Plate to substrate engagement affects solid density, tone gain at all coverages and dot circularity, when ink is transferred to a porous substrate.
- Dot coverage was shown to have an effect on the ink's ability to spread on the substrate.
- Speed had little effect on ink transfer, although it did have an effect on the 10 % tone gain, where low the ink volume on the dots combined with the shorter nip duration at higher speeds, to reduce the lateral spreading of the dots.
- Anilox to plate pressure reduced 40 % and 80 % tone gain, although it did not affect the 10 % tone gain. This was attributed to the small area of the 10 % dots on the plate, which were too small to accept sufficient ink for any effect of anilox to plate pressure to become apparent.
- Ink viscosity does not affect ink transfer, or ink spreading, when transferred to a porous substrate. However, ink viscosity did interact with plate to substrate engagement to affect the 40 % tone gain, due to the reduced ability of a thicker ink to spread.
- Results obtained using letterpress printing technology are applicable to the flexographic printing process.

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Variable data printing (VDP) quality aspects on fibre based packaging - an elementary print quality study on corrugated board

Marcus Rehberger[1,2,3], *Astrid Odeberg Glasenapp*[1], *Xiaofan Zhang*[2]

[1] Innventia, Stockholm, Sweden E-mail: astrid.glasenapp@innventia.com
[2] Royal Institute of Technology, Stockholm, Sweden E-mail: xfzhang@kth.se
[3] Tetra Pak Packaging Solutions AB, Lund, Sweden E-mail: marcus.rehberger@tetrapak.com

Abstract

Variable data printing (VDP) is a technique whereby certain information can be altered in an otherwise static layout with the help of a digital printing system, and in the packaging industry a wide range of applications are possible. Inkjet printing, due to its non-impact printing (NIP) principle, is the most suitable technique to be implemented in packaging production (van Daele, 2005). Only when printing high volumes is inkjet printing much more expensive than conventional printing (Viström et al., 2006). However, the advantages of inkjet printing could still be adopted by another approach.

At Innventia AB, the "HybSpeed Printing" project was initiated to study the combination of a conventional printing process with inkjet printing. The aim of the project is to assess the practicability of attaining high quality VDP at high speed on a variety of packaging papers for corrugated board production. The exploratory trials were conducted on a Kodak Versamark DP5240 in Örnsköldsvik, Sweden, in cooperation with the Mid-Sweden University - Digital Printing Centre (DPC). Nine different substrates, white top and pure white liner, single-coated, double-coated, kraftliner and testliner were printed at a speed of 2 m s^{-1}.

Rehberger et al. (2010) described in an earlier study that high-speed inkjet printing at 5 m s^{-1} has only an insignificant influence on the print quality. In this article, the influence of paper properties is discussed and it is shown that the paper quality has a considerable influence on the print quality. All paper qualities led to an acceptable print result at a medium print resolution. Speed is the most important factor for inline implementation of inkjet, but the tests revealed that the paper properties are most decisive for good print quality.

Keywords: hybrid printing, inkjet, variable data printing, packaging

1. Introduction

The primary function of a package is to protect and secure the goods inside from all kinds of impacts (Paine, 1992). Nevertheless, a successful package has to fulfil further important functions. Meyers and Lubliner (1998) state in their book "The marketer's guide to successful package design" that for the consumer "the package is the product". This means that: the package is representing and advertising the product and trying to catch the attention of the customers until they decide to buy this product (Calver, 2004; Meyers et al., 1998; Paine, 1992). In order to fulfil these tasks, the package needs to be informative but easily structured and to be able to address the buyer directly. Today, more than 10 years later, the package is still the product, but more products are on the market and the competition between the products has become more decisive. It is therefore becoming more difficult to catch the attention of the end-consumer and, depending on the product, the majority of all purchases are the result of in-store decisions (Ambrose et al., 2003; Calver, 2004; Meyers et al., 1998, Paine, 1992; Shimp, 2008).

New and more sophisticated tools for packages are necessary to catch the attention of the customer and the implementation of variable data print (VDP) on a package could be one solution (Viström et al., 2006). VDP is already in existence for newspaper and magazine delivery, where the main content is printed in offset and the variable address of each subscriber with inkjet (Dante et al., 2000; Stack, 2003). This idea, to combine two different printing techniques, is called "hybrid printing" and it could in fact be a combination of any available printing techniques, and not only two printing methods but several. This way of process combination is facilitating more features. Printing Organic Light Emitting Diodes (OLED) for use as displays requires three different printing methods and the process is very demanding in terms of technology (Kopola, 2009). Inkjet printing has a very diverse operative range and it can be applied on all kinds of substrates. It does not only print colour but also electronics, and the speed is mainly limited by quality aspects. Inkjet printing on packaging is a common method and it developed mainly from printed displays or case coding and bar-coding on fibre-based boards (Anon, 2003; Dante et al., 2000; Haines, 2005; McLoone, 2007; Polischuk, 2006). Common uses are cinema displays or in-store displays for product promotion. None of these are mass-produced and in most cases inkjet is chosen because of its ability to print larger dimensions and its flexibility for customizing prints (Hunter, 2001). These wide-format off-line inkjet units are however ineffective in terms of extra production steps; these units would unnecessarily increase cost and time consumption in mass production. To successfully use the inkjet technology in mass production, the keyword is: in-line inkjet printing units, where an inkjet unit is assimilated into the converting process of a packaging production line. Possible locations for integration could be the conventional printing unit, the die-cutter, the folder-gluer or the product-filling machine.

Inkjet printing heads are nowadays very sophisticated and with continuing development will soon be capable of meeting the requirements of high printing speed combined with high print quality and multi-colour prints (Birkenshaw, 2006; Stack, 2003). Thermal inkjet (TIJ) and piezo inkjet (PIJ) already show very good progress in print quality compared to conventional printing systems, but the lack of speed is still a critical factor. Both systems are widely used in wide- and grand-format printers, bar-coding and mailing applications (Anon, 2008; Lynn, 2009).

Continuous inkjet (CIJ), on the other hand, is, as Lynn (2009) describes in "A Xaar perspective on 'The inkjet DRUPA' ", capable of printing at high speed and dominates small character marking. CIJ would fulfil the requirements for in-line integration, but it is lacking in quality compared to TIJ and PIJ. A mix of all these systems would be necessary and, since speed is often more important for in-line integration than print quality, CIJ is the first choice to be used.

2. Test set-up

The Kodak Versamark DP 5240 is a CIJ and is capable of printing at a resolution of 240 x 240 dpi at a speed of 305 m min^{-1} (1 000 fpm). One of these printing systems is installed in a printing rig at the Digital Printing Center (DPC) in Örnsköldsvik, Sweden. A detailed explanation of this printing test rig and the accompanying printing layout have been described by Rehberger et al. (2010).

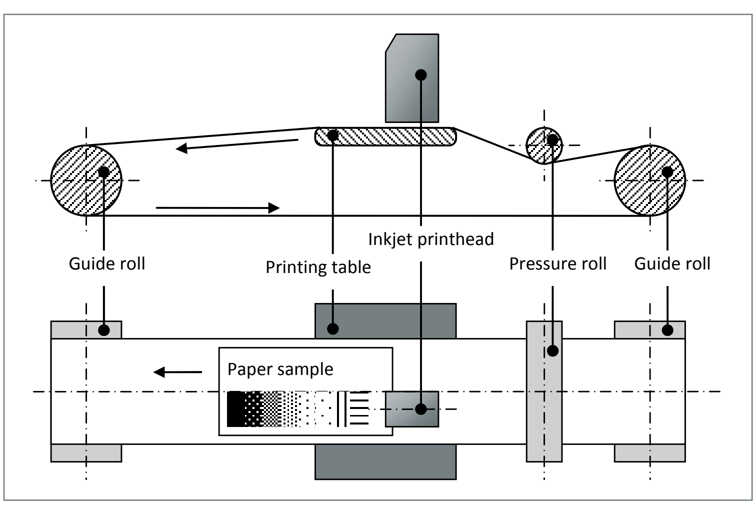

Figure 1: High speed inkjet printing test rig at DPC.
Kodak Versamark DP5240 inkjet unit printing on paper samples mounted on an endless belt

The system is designed as an endless belt and the paper samples are attached to this belt (Figure 1). The single-colour DP5240 system is equipped with a Printhead Interface Controller (PIC), and it prints with water-based dye ink (surface tension: 42 dyn cm^{-1} at 25° C) over a printing width of 2.71 cm (1.07").

The final printing was carried out at a speed of 2 m s^{-1} (394 fpm) with a black-coloured water-based ink. The papers were attached to the belt so that the printing direction corresponded to the direction of the paper production and thus the fibre direction.

The arrangement of a printing test requires not only a reasonable printing system but also a proper print layout. In this study, nine different papers were printed and, to assess their performance, the following print evaluations were chosen: line raggedness and thickness, area coverage, lightness, print mottle, print density and dot diameter. In addition, the absorbency, surface roughness and unprinted mottling of the paper were determined.

The print layout is shown in Figure 2 and it includes lines of different thicknesses (1, 2, 3, 5, 7, 10 px) and each line was printed three times in both longitudinal and transverse directions.

The text was printed in Times New Roman in 8, 10, 12, 18 and 36 px. The second part of the print layout was the grey tone; two different modes were used in Adobe Photoshop CS2 to create the grey tone boxes, which are regular half-tone (HT) and diffused dither (DD).

The stepping for both modes between the grey tones was 2 % between 0 % and 10 % and 10 % between 10 % and 100 % (see Figure 2).

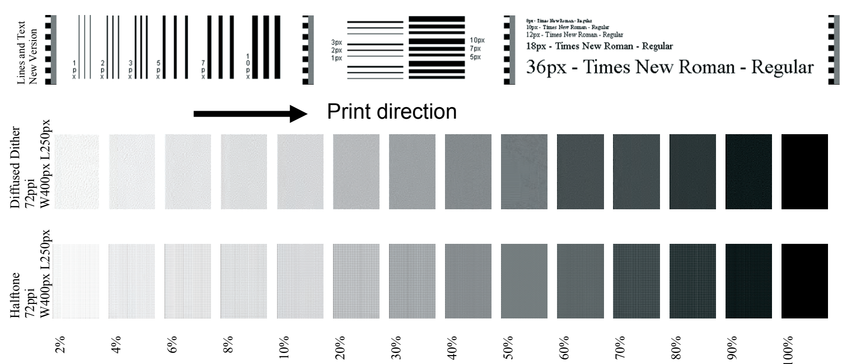

Figure 2: Print layout; top: lines (1-10 px) and text (8-36 px), bottom: grey tones in halftone and diffused dither (generated with Adobe Photoshop; W400 px = width 400 px and L250 px = length 250 px)

Table 1: List of papers

● Pure white, uncoated, 170 g m^{-2} (N1)
● White top, uncoated, 175 g m^{-2} (N2)
● Pure white, coated, 95 g m^{-2} (N3)
● White top, single-coated, 170 g m^{-2} (N4)
● White top, double-coated, 175 g m^{-2} (N5)
● Kraftliner, uncoated, 186 g m^{-2} (N6)
● Kraftliner, uncoated, 140 g m^{-2} (N7)
● Testliner, uncoated, 140 g m^{-2} (N8)
● Testliner, uncoated, 150 g m^{-2} (N9)

The variety of packaging materials on the market is extremely large and the choice is based on purpose and price. The paper type is an important factor influencing the runnability of inkjet printing.

A set of nine different types of papers was prepared for the test as listed in Table 1. These were two white / white-top uncoated liners (N1, N2), three coated liners (N3, N4, N5), two kraftliners (N6, N7) and two testliners (N8, N9).

The papers were conditioned at 23° C (73.4° F) and 50 % R.H. for 48 h before printing, stored in a light-protected casing, and they were kept in this environment until all the measurements and evaluations were completed.

3. Testing methods - paper

Two common techniques are available for measuring wetting behaviour, the Cobb test and the dynamic contact angle test (DAT). The Cobb test is commonly used in the industry, because it is a very simple method, the evaluation is very fast and the equipment is cheap. Nevertheless, it is a very rough method measuring absorption over a long time, and another test method is therefore required to test the wetting behaviour. The DAT-1100 by Fibro System AB, Sweden is a dynamic contact angle tester measuring the wetting behaviour when a de-ionized water drop with a volume of 4 µl (adjustable) is placed on the sample surface. It is equipped with a CCD camera to capture images of the drop during the wetting process with a maximum frequency of 1 000 Hz. The program measures the drop base b and the drop height h and calculates the contact angle Θ, drop volume V and drop area A from these two values over the set time range (Figure 3).

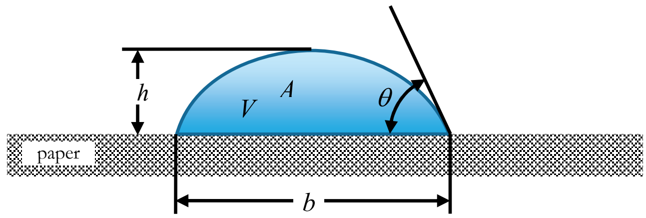

Figure 3: Diagram of the drop on the paper surface during the wetting process; drop base b and drop height h are measured and contact angle Θ, drop area A are calculated from these values

In the testing procedure, 8 drops were applied on each of four paper strips and, for each paper type (N1 to N9), a total of 40 drops were examined.

The Bendtsen and Print-Surf (PPS) method are commonly used in the pulp and paper industry to characterize the surface roughness of paper. Both methods were used on all the liners (N1 - N9), but the results were not significant. Kuparinen (2005) writes that Bendtsen method performs better on rough papers, whereas PPS is better suited for smooth papers. Test methods such as Atomic Force Microscopy (AFM) and Confocal Laser Scanning Microscopy (CLSM) are also capable of measuring surface roughness, but on an atomic- and nano-scale, which provides less information about wetting behaviour or print quality. The FRT MicroProf© is a non-contact method and surface height profiles indicating roughness and waviness on a macro- and micro-scale can be acquired. Its principle is based on chromatic aberration where white light is split into different colours focused on different heights. The light reflected by the surface is analyzed and the data are computed into a topographical image (Rehberger et al., 2006).

For this test a resolution of 3 x 10 000 px (x-y) was chosen in a range of 80 x 20 mm, leading to a resolution of 2 µm in the y-direction. The detection rate of the sensor was set to 100 Hz, because a detection rate above 300 Hz could generate missing values in the height profile and thus falsify the roughness results.

In Table 2, where are listed the paper tests used, the first two methods characterize physical properties of the paper and the last two optical properties. Both paper mottling and paper lightness were measured with the same device as described in the next section.

Table 2: Testing methods for paper properties

Analysis	Measurement system	Analysis Software
Surface roughness	MicroProf® (FRT, Germany) with Chromatic Sensor CWL (z measuring range 300 µm)	Measuring: FRT Acquire (FRT, Germany) Evaluation: FRTcalc v1.2 (Innventia AB, SE)
Wetting behaviour	DAT-1100 (Fibro, Sweden)	DAT v3.3 (Fibro, Sweden)
Paper mottle	see "print mottle" Table 3	
Lightness L*	see Table 3	

4. Testing methods - print

Table 3 lists all the tests used to quantify print quality. The Techkon SpectroDens was utilized to measure both lightness and print density and it was applied both on unprinted and printed areas, the 40 % half-tone (HT40), 40% diffused dither (DD40) and fulltone (100). The settings for the lightness measurement were "LAB-Whiteness/Yellowness", Polarization filter "Off", "Absolute White" reference, Density filter for "DIN 16536", Yule-Nielsen factor at "1.0", "D50" illuminant and "2 degree" observer. Each paper type was measured 5 times on 3 different samples, giving 15 values for each sample area (paper, HT40, DD40 and 100).

The settings of the SpectroDens and the procedure for the print density measurement were similar to those used in previous tests, except that the device settings were changed to "Densities CMYK" and polarization filter "On".

The area coverage was calculated as described in detail in Kipphan's "Handbook of Print Media" (2001) from print density data using the equation:

$$FD = 1\text{-}10\text{-}DR1\text{-}10\text{-}DV \cdot 100\,\% \qquad [1]$$

where:

FD = area coverage in print

DR = halftone density

DV = solid tone density

Mottle is described by Johansson (1999) as optical inhomogenity, an unevenness in optical density and print gloss. It appears in solid-tones or smooth image regions. A flatbed-scanner-based analysis system is used, where the coarseness is determined by applying a band-pass analysis, and the result is then divided by the mean reflectance (Fahlcrantz et al., 2004).

The software used, called STFI-Mottling Expert 1.0, can be run on any PC-System with almost any flatbed scanner.

Table 3: Testing methods for print properties

Analysis	Measurement system	Analysis Software
Lightness L*	Spectro-Densitometer: Techkon SpectroDens Premium SW v6.06; HW v1 (Techkon, Germany)	Techkon SpectroDens Connect v1.0 (Techkon, Germany)
Print density		
Area coverage		see equation [1]
Print mottle	Flatbed scanner: Epson Perfection V750 Pro with SilverFast Ai v6.5.0r4e	STFI-Mottle v1.2 (Innventia AB, Sweden)
Line raggedness		PrintSharp v1.02 (Innventia AB, Sweden)
Line thickness		
Dot diameter	Optical microscope: Axioplan 2 (Zeiss, Germany)	ImagePro-Plus 4.5.1.22 (Media Cybernetics, USA)

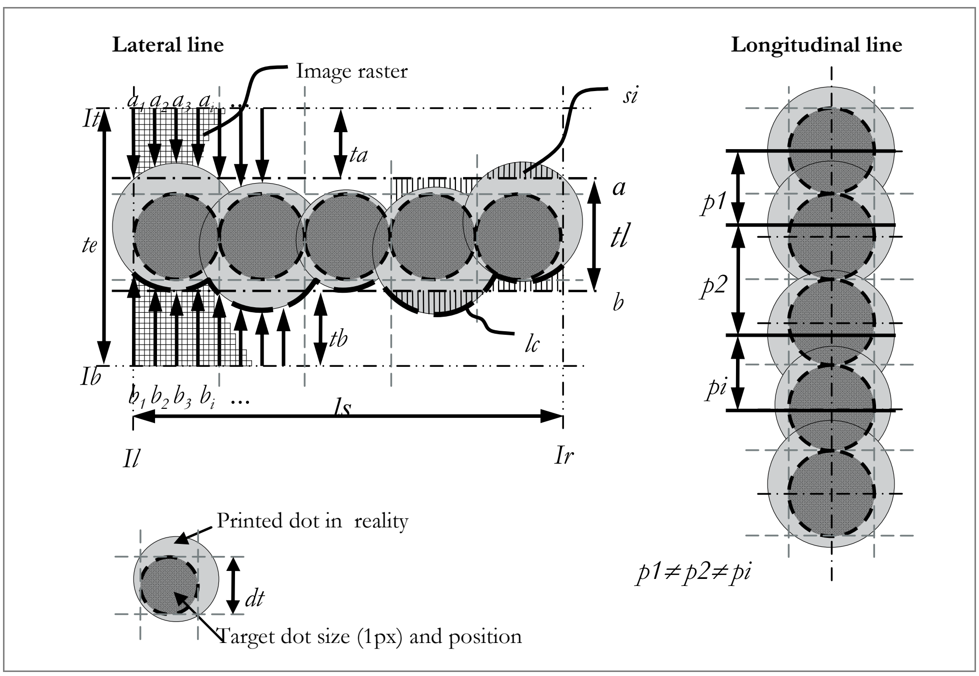

Figure 4: Diagram of two 1 px lines within an image raster and the top I_t, bottom I_b, left I_l and right I_r image borders. For the lateral line (left), the calculation of raggedness, line thickness and dot deviation in form and position from the target dot is shown. The longitudinal line (right) shows the dot deviation p_i in the printing direction. The printed lines are scanned and rasterized as illustrated in the diagram

Human perception at normal viewing distance is especially sensitive to variations within the spatial wavelength range of 1-8 mm, and other wavelengths are therefore excluded from the frequency analysis. The mottle is reported as the percentage coefficient of variation of the reflectance. Two samples from each paper type were tested and measurements were made on the plain paper, 40 % HT and 40 % DD and full-tone.

Line raggedness measurements analyse the edge / contour of a printed line, which is an important factor in the visual readability of small text fonts and the technical readability of barcodes. To measure raggedness, the samples were scanned as uncompressed 8 bit tiff-images with a flatbed scanner in a resolution of 300 x 300 dpi. Figure 4 is a diagram of a 1 px line in the lateral and longitudinal directions, showing the target diameter of the dots and examples of dots deviated in area and position, factors which influence the shape of the edge and the raggedness of a line. The PrintSharp Tool (Innventia AB) is capable of determining line raggedness 1 and 2 and line thickness by analysing the scanned image of a line, as indicated in Figure 4. First the tool seeks for the contour line *lc* by scanning inwards pixel by pixel from the image border (*It* and *Ib*) and calculates the median (*a* and *b*) of both edges of the line. The tool has a built-in algorithm which determines the optimal threshold taking into account the back-ground noise of the paper.

The raggedness can then be calculated in two different ways. Raggedness-1 (*R1*) given by Equation [2] is the ratio of the actual contour length (*lc*) to the straight line *(ls)*. The perfect contour is a straight edge having *R1=1*.

R1 = lcls [2]

where: *R1* = raggedness-1; the relative excess contour length in relation to a straight line
lc = length of contour line [µm]
ls = length of straight line [µm]; distance between the image borders *Il* and *Ir*

Raggedness-2 (*R2*), given by Equation [3], is the standard deviation, and is analogous to the *Rq* (root mean square) surface roughness. The distances *si* between the mean line and the associated contour line are determined and the standard deviation *R2* is calculated. In this study, *R2* has been used as a measure of the line raggedness.

R2 = 1ni = 1nsi2 [3]

where: R*2* = raggedness-2 [µm] the standard deviation of the contour from the mean line
si = distance between mean line and contour line [µm] in y-direction; *a* ≙ upper mean line and *b* ≙ lower mean line
i = index number of distance points in x-direction
n = total number of pixels in x-direction

A further module of the PrintSharp Tool is the calculation of the line thickness (*tl*), i.e. the distance between the medians (*a* and *b)* of the line:

tl = te-ta+tb [4]

where: tl = line thickness in [µm]; distance between the upper *a* and lower *b*
te = distance in [µm] between the upper *It* and lower *Ib* image borders in y-direction
ta = distance between the upper image border *It* and *a* in y-direction in [µm]
tb = distance between the lower image border *Ib* and *b* in y-direction in [µm]

To determine the average size of the printed dots, microscopy images in the 10 % gray tone area were taken.

Images were captured by an optical microscope Zeiss Axioplan 2 using a dark field technique in reflected light, and analyzed using the ImagePro-Plus (Media Cybernetics, Inc., USA) commercial image analysis system. This program measures the diameter of the printed dot dp at five different angles and calculates an average diameter. The diameter of the theoretical dot dt is equivalent to the distance between the dots which is the resolution of the print head (see Figure 4). The Kodak Versamark DP 5240 has a resolution of 240 dpi which is a screen width of 105.8 µm.

From the two diameter values, first the area coverage in print is calculated:

Fp = Ft·ApAt = Ft·dp2dt2 [5]

where: *Ft* = target area coverage [%]
Fp = area coverage in the print [%]
At = target dot area [µm²]
Ap = dot area in the print [µm²]
dt = target dot diameter [µm]
dp = dot diameter in the print [µm]

and then the geometrical dot gain *zg* is calculated:

zg = Fp-Ft [6]

where: *zg* = geometrical dot gain in [%]

5. Results

The surface roughness (see Figure 5) of the testliners (N8 and N9) was very high and according to Figure 6 and Figure 7, both these papers had a very open and porous fibre structure, since almost half of the applied 4 µl water drop was apparently absorbed into the fibre structure of the testliners.

The kraftliner N6 had a slightly lower *Rq* than the testliners, but N7 had a much smoother surface roughness. Data showing the treatment of the papers were not available, but it can be presumed that N7 was sized. The absorption test on the N7 liner shows, despite its very low surface roughness, a very hydrophilic surface, whereas N6 with its very rough surface was one of the most hydrophobic surfaces tested. The N6 liner must have a treated surface in order to have such high hydrophobic values.

The uncoated pure white (N1) and white top (N2) liners were presumably treated also. They had a relatively low surface roughness and, like the N6 liner, they were the most hydrophobic papers in the test with a constant contact angle greater than 98 degree and a very low water absorption.

The papers N3, N4 and N5 had, due to their coating, the lowest surface roughness, the N3 liner being the smoothest paper. In the wetting test, all three liners show a very high drop volume, N3 liner being the highest. Figure 6 shows that the contact angle rapidly decreases, which means, in combination with a constant drop volume, that the drop is spreading on the paper without being absorbed into the paper. The conclusion is that this can lead to similar effects with the inkjet drops and cause dot gain.

Mottling was measured both on the plane paper and on printed samples. The gray area in Figure 8 represents the paper mottle and shows clearly that there was almost no mottle on the coated (N3-N5) and white uncoated papers (N1-N2). The kraftliners (N6-N7) had a paper mottle of about 3.9 % and the testliners (N7-N8) a value up to 4.4 %. The unevenness in density was much more visible on the brown kraftliner. In the test-liner, particles from the recycling process could be seen.

The print mottle results differ from the paper mottle. The coated papers had the highest print mottle values in all the regions tested. The cause is the low water absorption (see Figure 6 and Figure 7) and in full-tone

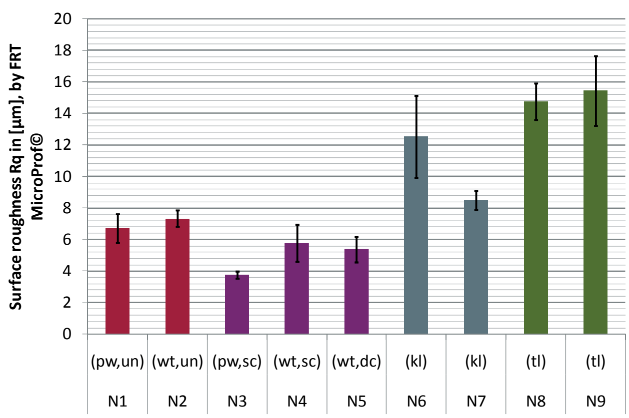

Figure 5:
Surface roughness values of all papers in this test.
Abbreviations pw = pure white, wt = white top,
un = uncoated, sc = single coated, dc = double coated,
kl =kraftliner and tl = testliner

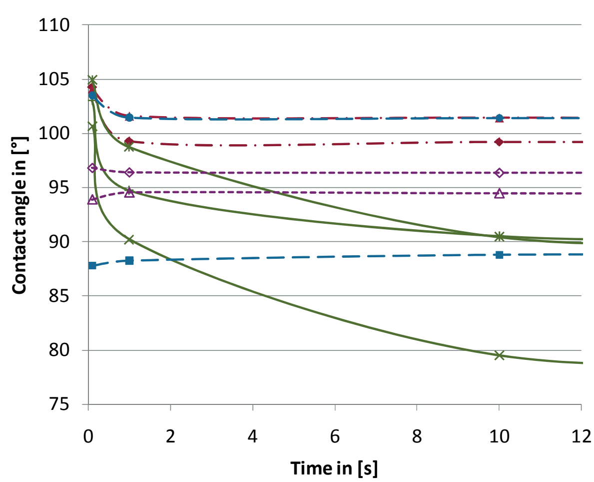

Figure 6:
Average values of the contact angle as function of time

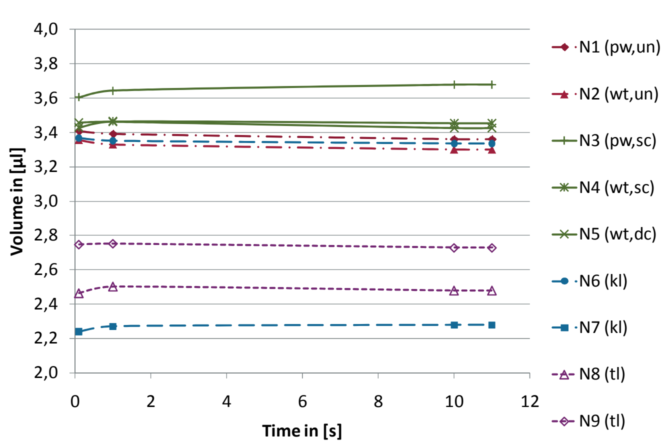

Figure 7:
Average values of the drop volume as function of time

the drops join and form brighter and darker spots due to ink spreading. In half-tone, due to the slow absorption, some drops join and form bigger drops and this lead to slightly darker and brighter areas. The other papers are more absorptive and have a static contact angle and this could be the primary effect that the print mottle is lower than on the coated papers. The white uncoated N1 and N2 papers had the lowest print mottles. Although the kraftliners and testliners had the highest paper mottle, the print mottle values in the 40 % area were similar to the paper mottle and the full-tone print mottle was only slightly higher. It thus seems that paper mottle has only a minor influence on print mottle values, because the print, due to its high contrast on the paper, covers the paper mottle.

Print density is related to the ink film thickness on the print and, as expected, the coated papers had the highest print density on both regular half-tone (Figure 9) and the diffused dither (Figure 10).

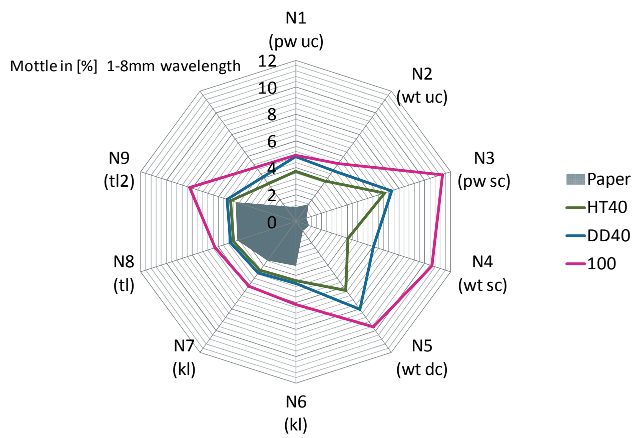

Figure 8: Mottle in the wavelength range of 1-8 mm. Analysis of the plain paper, 40 % half-tone (HT40), 40 % diffused dither (DD40) and full-tone (100) areas

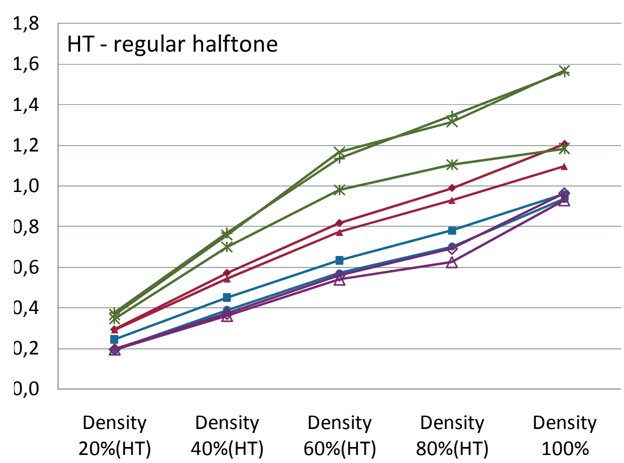

Figure 9: Print density measured on 20 %, 40 %, 60 %, 80 % regular half tone and 100 % full-tone

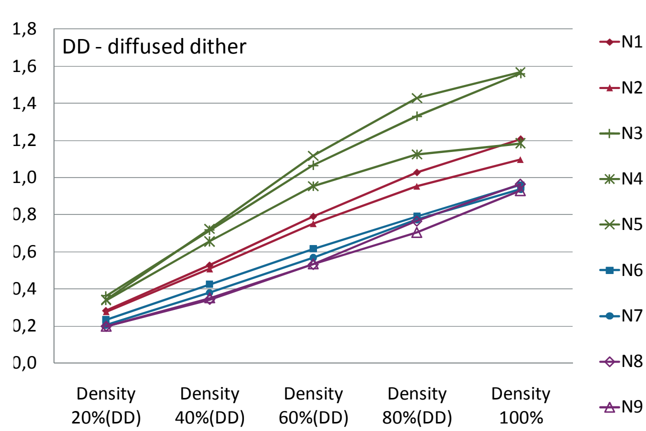

Figure 10: Print density measured on 20 %, 40 %, 60 %, 80 % diffused dither and 100 % full-tone

The uncoated pure white and white top liner (N1, N2) had lower print density values, and the lowest values were obtained on the testliners and kraftliners.

Print density and absorption behaviour can be related to each other, and if the DAT values show a low absorption, the print density should be high, because the ink drop is absorbed less into the paper and builds a thicker ink film layer. This was observed for the coated papers and uncoated white papers, but not for the brown kraftliners and testliners. The kraftliner N6 had a very hydrophobic surface but the print density was low. The kraftliner N7 had a print density similar to that on N6, but in wetting behaviour (see Figure 7) and surface roughness (see Figure 5) these two liners exhibited opposite trends.

Figure 11 and Figure 12 show the calculated area coverage plotted against the nominal coverage and the coated papers (N3-N5) showed the greatest increase in area coverage compared to the ideal reference. The pure white (N1) and white top (N2) papers had the next highest increase in area coverage and, as expected, the kraftliners (N6, N7) and testliners (N8, N9) had the lowest values, although the brown paper N6 had an area coverage almost as high as that of the uncoated white papers.

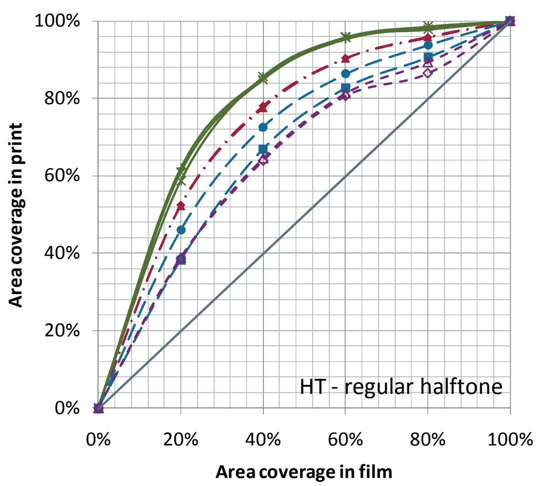

Figure 11: Calculated area coverage of regular halftone

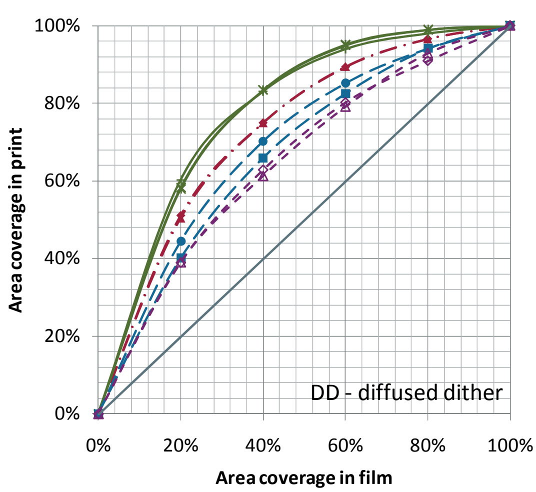

Figure 12: Calculated area coverage of diffused dither

Norberg (2006) concludes that the whiteness of a paper is an important quality parameter, because high paper whiteness increases the colour gamut and the contrast (print density). Figure 13 shows that papers N1-N5 had a high L* level greater than 90 whereas the brown papers N6-N9 had an L* value between 57 and 65.

The papers N1 and N2 have relatively high lightness values, but these papers were uncoated and the lightness values of the print were therefore also high. The uncoated surface absorbs a large part of the ink into the top surface structure of the paper and makes the print appear pale. This was not the case for the coated papers, where the difference in lightness between the plain paper and the 40 % half-tone print was much greater than for the other papers. In full-tone the papers N3 and N5 had the lowest lightness values, whereas the L*-value of the coated N4 liner was similar to that of the uncoated white liners. The same paper shows a similar effect in print density.

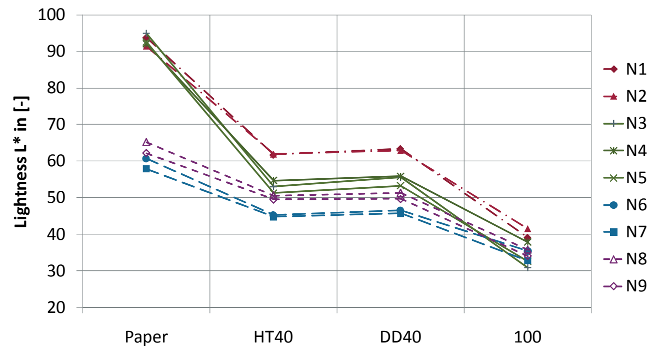

Figure 13: Lightness L of unprinted papers and of paper printed in 40 % regular halftone (HT40), diffused dither (DD40) and fulltone (100)*

The dot diameters in Figure 14 do confirm the high density values on the coated papers and thus the large decrease in lightness.

In this diagram, the target dot diameter is indicated as a black solid line and the excess is the geometrical dot gain *zg*. The right hand axis shows the drop volume at 1 s from the absorbency test, and the coated papers had the largest drop volume. The coated papers have the highest geometrical dot gain with 13 %. The papers N1 and N6 have a geometrical dot gain of 8 %, N2 7 %, N7 3 %, N8 2 % and N9 1 % and for all papers, except the testliners, the drop volume showed the same trend. The reason for the inverse trend in the case of the testliners may be their high surface roughness and open structure.

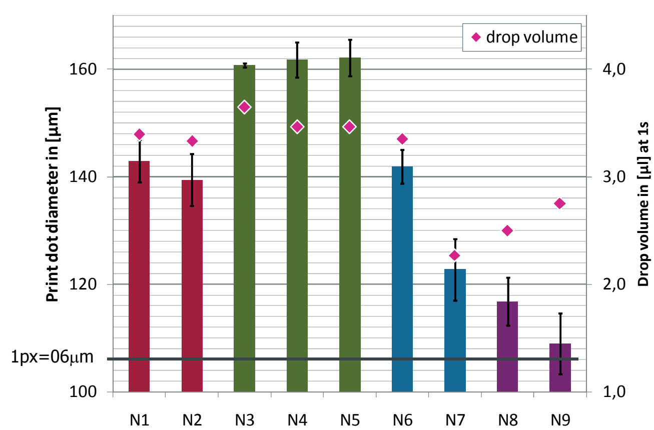

Figure 14: Print dot diameter of the 10 % greyscale area. The 1 px line indicates the target size of a single dot and the single points show the drop volume after 1 s in the absorbency test

Besides the dot diameter, the shape of the dot is also a very important criterion for good print quality. Figure 15 illustrates examples of dots on each paper type. The uncoated papers all have a similar dot shape, where the ink follows the fibre structure and forms a rough edge, where only the roughness and wetting behaviour affect the roundness and size. The coated papers, on the other hand, have a very round shape and the edges are very sharp.

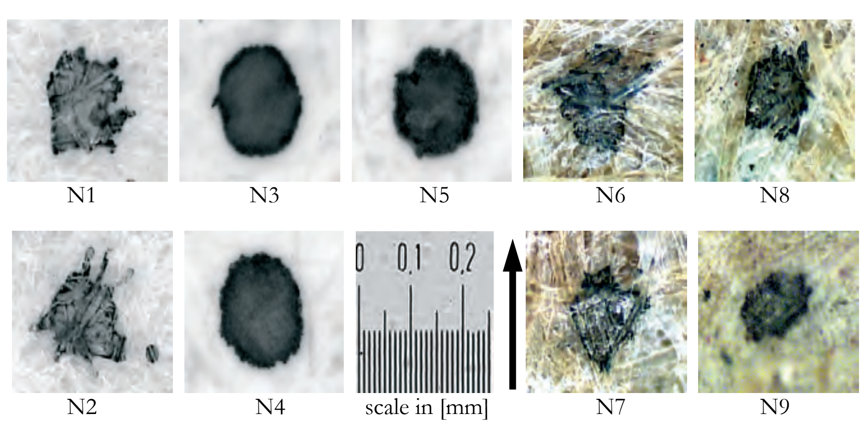

Figure 15: Microscope images of single dots from the 10 % tone on all the papers (image treated for better illustration). The arrow indicates the printing direction, which is the same as the paper fibre location

The deviation in diameter of the printed dots also affects the line thickness. Figure 16 shows the thickness of the longitudinal printed lines (y-axis) plotted against the lateral lines (x-axis).

The solid black line represents the target line thickness for the two directions. All the papers had a greater line thickness increase ΔL when the line was printed in the longitudinal direction and above 3 px the difference was constant. In the longitudinal direction, the number of print nozzles determines the print line thickness (1 nozzle = 1 px line) and no triggering can change the distance between the dots. The thickness of the lateral lines is defined by how often the inkjet nozzle is triggered. The 1 px line is the only line which is not affected by the triggering and has a similar deviation in both directions defined mainly by the diameter of the dots. Lines based on two pixels or more are influenced by overlapping/gaps. In the lateral direction, the 2 px line already shows a small ΔL and this value decreases the thicker the lines. Above 5 px, ΔL for the testliners is negative and for the kraftliner N7 it is almost zero.

Line thickness can also be influenced by the line raggedness, because a ragged line can appear thicker than it is. Line raggedness is important because it affects the readability of small text elements or the readability of bar codes. The results are illustrated in Figure 17 for lateral lines (LQ) and in Figure 18 for longitudinal lines (LL) and both show similar trends.

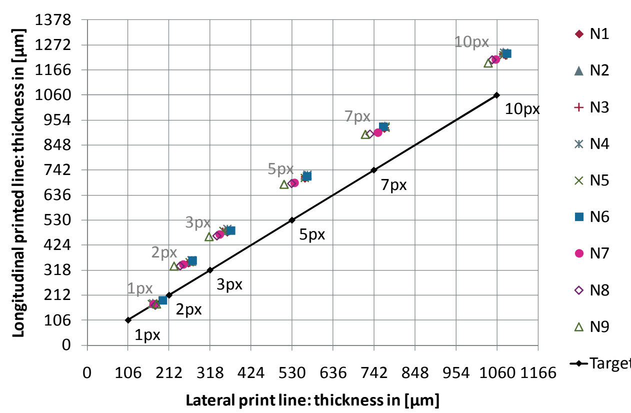

Figure 16: Line thickness in longitudinal direction vs. line thickness in lateral direction. The solid line is the target line on which the target points are marked (above: actual line thickness, below: target line thickness)

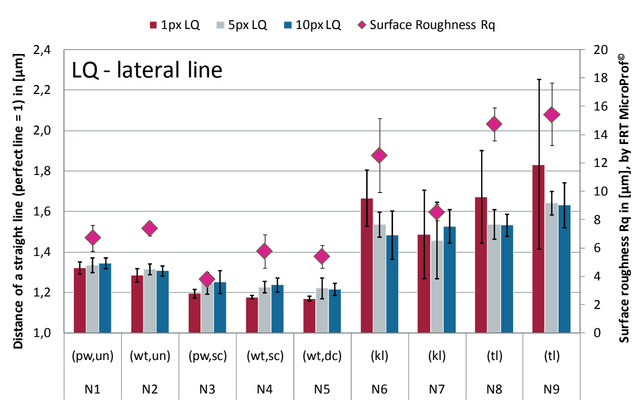

Figure17: Raggedness-2 for the line thicknesses 1 px, 5 px and 10 px of lateral (LQ) printed lines. The surface roughness (right scale) influenced the line raggedness

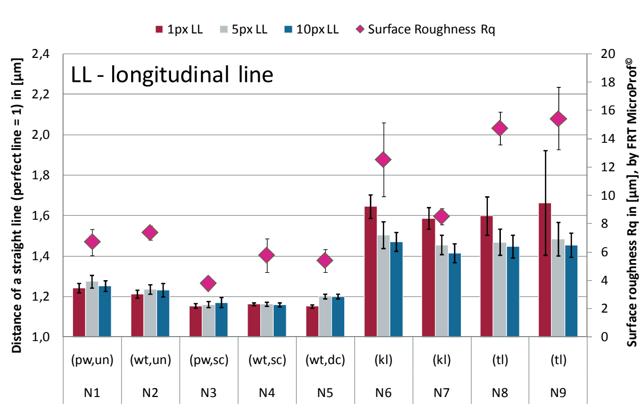

Figure 18: Raggedness-2 results for the line thicknesses 1 px, 5 px and 10 px of longitudinal (LL) printed lines. As in Figure 17, the surface roughness results are included

The most ragged lines were found on the testliners and kraftliners and especially the 1 px lines. The lowest raggedness is found on the coated liners and in this case the 1 px lines were the least affected. The diagrams also show the surface roughness values and its impact on the raggedness of the lines is evident.

6. Conclusions

The printability and versatility of packaging papers was tested to see how different types and treatments influence the result. In an earlier study (Rehberger et al., 2010) two papers were tested (N4 and N7) to investigate how print quality is affected by the speed setting, but the influence of the speed was minor compared to the influence of the choice of the paper. Surface roughness and wetting behaviour appeared to influence the print properties in high speed inkjet printing the most. In this second part of the study, nine papers have been compared to see how the physical properties of the paper influence the print quality.

The settings of the inkjet system were kept constant for all papers, in order to make quantitative conclusions possible, but the consequence was that an excess of ink was printed onto the papers, causing very high print density values. Changes in the ink formulation and in the drop size would have been necessary to achieve optimal print quality on each paper. The coated paper showed an increased print mottle and dot diameter, but the printed dots and lines had perfectly sharp edges. The ink amount had less effect on the kraftliners and testliners, because these papers had better absorption properties, but the impact of the surface topography on the print was much greater. The uncoated white liners have been bleached and further treated to enhance print quality. In tests like line raggedness, they had almost the same print quality as the coated papers, but in other tests the effect of the non-coated surface was evident.

Inkjet technology is in principle capable of achieving a print quality similar to that given by conventional printing machines. The difficulty of achieving high resolution at high speeds is the only obstacle preventing inkjet technology from being used for high quality mass production. Multiple single-pass-heads including a very powerful RIP-system (raster image processor) would be necessary to achieve this, but such powerful systems are as yet available only for special purpose machines and are too expensive for use in daily production.

Abbreviations

VDP: Variable Data Printing
TIJ: Thermal inkjet
PIJ: Piezo inkjet
CIJ: Continuous inkjet
PIC: Printhead Interface Controller
R1: raggedness-1
R2: raggedness-2
NCS: Natural Color System
DAT: Dynamic Contact Angle Tester
HT: half-tone
DD: diffused dither
HT40: 40 % regular half-tone
DD40: 40 % diffused dither
LL: longitudinally printed line
LQ: laterally printed lines

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Topicalities

Edited by Raša Urbas

Contents

News & more

New ISO standard 12640-4:2011

The Technical Committee (ISO TC 130) of International organization for standardization has published a new standard ˝ISO 12640-4 Graphic technology-Prepress digital data exchange-Part 4: Wide gamut display-referred standard color image data [Adobe RGB (1998)/SCID]˝.

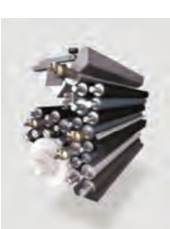
ISO 12640-4:2011 specifies a set of standard wide gamut display-referred color images, that can be used for the evaluation of changes in image quality during coding, image processing (including color re-rendering and color space transformations, compression and decompression), displaying on a color monitor and printing. These images can be used for research, testing and assessing of out-put systems such as printers, color management systems and color profiles.

The images of Part 4 supplement the images of Part 1 (CMYK data), Part 2 (sRGB gamut images), and Part 3 (large gamut images encoded as CIELAB data). Part 4, available on DVD, includes 14 natural images and two synthetic images (test charts).

ISO 12640-4 can be obtained from ISO member national organizations. More information is available on www.iso.org.

IPA-free printing system

Reducing the use of IPA (Isopropyl alcohol) because of its negative side effects, which with evaporation causes health and environmental problems, has for many years been a concern of the printing industry. The new IPA-free system has been therefore developped, as an environmentally friendly and cost-effective solution with new dampening rollers, improved measuring technology and alcohol substitutes.



The new package includes special dampening rollers with modified surface materials and structures and an extended range of features. For alcohol-free printing quality of water must be consistent showing an overall hardness of between 8 and 12 dH. Fluctuation of water hardness could be treated if needed for example in reverse osmosis plant. The new dampening rollers ensure that a sufficient quantity of dampening solution is very evenly distributed over the printing plate, thereby achieving an optimum ink-water balance. Peripheral unit is equipped with digital metering technology for dampening solution additives, by which an extremely precise accuracy of +/- 0.1 % is achieved. Unit has integrated a filtering system with improved elements for dampening solution micro-filtration.

The drupa Prize

Starting in 1978, Messe Düsseldorf, the organiser of drupa, is honoring outstanding monographs at the Faculty of Humanities at the Heinrich Heine University in Düsseldorf. Each year the drupa Prize is awarded by a high-level specialist committee.

This year's drupa Prize goes to Ulf Tranow from Düsseldorf for his doctoral thesis "Solidarity and Sociological Analysis - a Theoretical Contribution to the Concept of Solidarity".

New atlas of fonts for smart technologies

Users of smart devices can now enjoy the advantage of a new application - Font Book Atlas. With the use of new tablet application over, 620 000 fonts are available. Application represents advanced version of font catalogue with more than 35 000 pages.

The Atlas is published by Fontshop.

Low durability outdoor inks

High performance solvent-based inks are compatible with different print head technologies. Inks are designed for outdoors with durability of about one year. Lower cost, great adhesion to all types of media and greater color gamut in comparison with OEM inks are some of the outstanding benefits. Triangle LD inks will be of great interest for products where long term durability is not required.

Ink key presetting solutions for automated production

Xitron Keysetter Pressroom workflow solution offers a variety of options for providing ink key presetting for presses from a number of manufacturers including Heidelberg, Komori, manroland, KBA, Mitsubishi, Sakurai, Shinohara and Adast. It is available as a module of an existing prepress workflow or as self-supporting application system which enables integration in any existent operational system.

New module for web printing

Already existing working system for web printing Prinect web-to-print manager is updated with the new module. It will be for the first time introduced by Heidelberg at Graph Expo 2011

The module will enable automation of processes like creating different methods of realization, selection of suitable technology for order realization, etc. Manager's function will include direct access to central data base Prinect MIS workflow system. Confirmation of delivered files on distance will be possible through adjustable web portals for order deliveries.

Certified family of papers

German manufacturer Deutsche Papier has remodeled the whole program of Fizz color papers which is now available in 26 color shades in 80 to 270 g/m^2. The color shades include intensive as well as pastel colors. The papers are suitable for different applications - commercial communication, leaflets, brochures and business printing. Papers can be printed with different techniques like inkjet printing, laser printing etc.

3D Designjet printer

A new step into the world of computer designing is and 3D printing is MCAD (Mechanical Computer Aided Design).

HP has expanded its Designjet portfolio with new first model of 3D printers. This printing solution enables fast and expense efficient 3D realization. At the same time it represents new standards of 3D printing in sense of integration in different working areas and reliability. The new printer is also suitable for educational purposes.

Mobile application for designers and printers

This new free mobile application enables easier daily work of designers and print producers. Application offers simple acquirement of basic graphic parameters as: DIN formats, screen rulings, scan resolutions, file sizes and much more. These features are supplemented by a practical paper and brand overview, with which the ideal paper for print project could be found. The application was developed and supported by Papierfabrik Scheufelen, manufacturer of highly bleached coated papers.

The control station enables overview of the dampening solution quality, with developments in pH value, conductivity and temperature displayed in real time. The system also shows different parameters as consumption, levels for water, IPA and dampening solution additive. Low concentration of IPA may be required when printing special colors and spot colors or when using non-absorbent substrates.

The system is developed by Heidelberger Druckmaschinen AG. An updated IPA-free printing package for UV print applications will be available by drupa 2012.

Ecofriendly paper

Environmental and society responsibility are the main purpose and scope of the new range of coated fine papers. This 100% recycled fiber content paper is suitable for prestigious printing, FSC® certified According to its properties "Respecta 100" coated papers present a suitable solution for communication focusing on the environment or company environmental, economic and social sustainnability.

In comparison with production of common coated papers, each ton of "Respecta 100" gives reduction of 100 kg of CO_2 emissions, which is a great contribution the environmental sustainability. Paper ensures good performance, high gloss, excellent brightness, impeccable chromatic performance, low impurity content and low ash level.

"Respecta 100" is a new product of Italian manufacturer of coated papers Burgo.

Mobile access for color communication

Pantone has announced two new mobile applications which will offer a great support in design industry.

myPANTONE for Android brings iPhone application for capturing, creating and sharing color palettes to the Android platform, giving graphic, digital, multimedia, and industrial designers access to all the Color Libraries. Each color in this application includes sRGB, HTML and L*a*b* values. The application also automatically generates a variety of harmonious color combinations. Details captured with Android's built-in camera can be directly analyzed and similar colors among the various libraries could be found.

myPANTONE 2.0 is another application upgraded from previous version with several enhanced features, including color calibration, tools to improve the appearance Colors on screen, CMYK support, access to ICC color-managed values and the ability to print color palettes straight from the iPhone. myPANTONE 2.0 enables calibration of iPhone display to view color-corrected PANTONE Colors.

Joined solutions for direct mobile printing

Printing of documents from mobile devices becomes a reality. As announced from Canon, first step of mobile development will be the support of multifunctional solutions imageRUNNER Advance in Fiery's Controller Image-Pass and Color-Pass with mobile basis. Mobile solutions will be combined in one package as Direct Mobile Printing Solution.

Using Fiery's Controller direct printing will be possible from Apple mobile devices like iPad, iPhone or iPod Touch. EFI´s solution for printing through mobile devices is compatible with Apple iOS operating system which - from the user's point of view - means that all users of Apple mobile devices will be able to see the availability of printers with mobile printing service. With just one click a printer could be chosen and even their availability could be seen. Documents will so be printed easily, directly and on demand.

Software solutions for Order Lifecycle Management (OLM) in the graphic arts industry

Three solutions are available for the Order Lifecycle Management. First is FrontDesk, which represents an interface between the customer and the printer. Basically it provides a web-to-print portal that offers customers file upload and download facilities. Besides it assures comprehensive job interaction, from on-line ordering through all stages of tracking, proofing and approvals to delivery of the completed work. Optional components include integrated soft proofing and annotation systems from industry-leading vendors, on-line editing and variable data, and powerful store profiling tools.

The second solution, FaceLift, provides compliant integration of the highest level between different production workflows, MIS/ERP systems, third-party websites, external databases and other sources of digitally held information. It enables total transparency of what is happening to the job, between the initial order and its delivery. Users can create their own templates to encompass every stage of the order's lifecycle, regardless of the printing process or product.

The third one is FileForce, which connects multiple production or printing sites within an enterprise environment, resulting in the ability of balancing and file sharing between sites. It does not require a centralized file server or DAM system, but instead works in conjunction with local file servers at each location. File versions can be moved, copied, harvested, scrapped, archived and tracked precisely across multiple sites as revisions occur throughout the order lifecycle. Files are managed highly effectively.

All versions operate via web browser technology and provide vendor-independent solutions based on industry standards such as JDF/JMF and SQL. Hybrid Software will demonstrating the latest version of OLM at LabelExpo Europe and later at drupa 2012.

New platform solutions in web offset printing

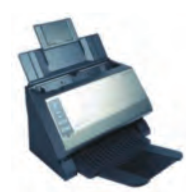
On the technology forum in Bern, Switzerland manroland presented two new platforms which emphasize the energy-efficient design of the press and the drive system with greater reductions in net CO_2 levels. These new solutions represent a wish to minimize waste during change-overs, fast production changes, InlineRegister Control systems, as well as product enhancements such as coatings, special colors, scents, and imprints.

The first one - HiPrint presents the solution providing a good price/performance ratio for 16-page printing. It is mainly designed for emerging markets, which is paramount in the highly competitive market of 16-page printing.

The second one - DirectDrive is on the other hand very flexible; it offers automated reproducibility for all print run sizes. This platform is geared toward the high-end market.

A multipurpose scanner

Sheet-fed document scanner DocuMate 4440 offers duplex scanning performance up to 80 images per minute (40 pages per minute), plastic hard card scanning, Kofax VRS image enhancement and ultrasonic double feed detection.



The scanner is mainly designed for big public services (healthcare and insurance companies) with specific scanning requirements which demand different imaging techniques. With its advanced features, the scanner helps eliminating cumbersome, expensive and time-consuming paper-based processes.

The scanner allows users to scan to the chosen destination, eliminating multiple steps usually required to save scanned documents in popular file formats. Using a set of links users are able to scan and automatically upload earth-bound documents to popular cloud destinations.

DocuMate 4440 is a product of Xerox Corporation.

Color Innovation Center

Xerox recently opened a new Color Innovation Center in the Greater Philadelphia region. The center features innovative color products and services, thus enabling current and prospective commercial printers and corporate customers one-stop access to the latest digital color technology. Center demonstrates how advancements like cross-media campaigns, QR codes, photo applications and workflow automation are transforming the world of print. Products featured in the center include color workflow solutions, available for both, PC and MAC environments.

Improving digital flexo technologies

New digital flexo solution released by EskoArworks as HD Flexo 2.0 improves the screening, delivering exceptional printing quality throughout the entire tonal range including highlights with gradients down to zero, stable midtones, and higher ink density solids. In addition, the innovative development of creating flat top dots generates sharper definition for outstanding image results.

New feature of adhesive label papers

A specially developed barrier coating on the adhesive label papers prevents the adhesives from penetrating the label from the reverse. The end result is a clear and consistent print image on the calendered surface of the label. Prolabel Anti-Staining is developed by German manufacturer of special papers Drewsen Spezialpapiere.

LAM - laser active material for labels

Newly developed self-adhesive material Herma LAM is designed especially for inscription with CO_2 lasers. Material is ideal for labels dispensed in inhospitable and dusty production environments. The protective coating assures non-smudge and scratchproof printing.

Wide format printing for textiles

Wide format printing system on textiles Teleios Grande (LFP) assures 330 cm width of prints with the latest technology of printing heads. System supports special SPC colors by Dgen as well as textile pigment inks and disperse inks.

Full-color high speed inkjet printing system

The new 2800 Inkjet Color Continuous Feed Printing System for comercial and data printing has achieved the fastest output speed of 200 meters per minute in full-duplex. The system uses 600 by 600 dot per inch piezo drop-on-demand inkjet heads with pigmented aqueous inks.

The whole system is very compact with a length of the base of only 7.5 meters. It enables duplex printing without additional printer, thus saving the installation space by 50 percent. The new system's full-color variable data printing feature with enhanced reliability should contribute to improving of communications between customers and corporations in industries that need to issue such documents as account statements and invoices. The touch panel allows users to check the status of the printing system, printing jobs and RIP performance.

Beside high-speed output, the system enables printing of variable data on each page, the newly-developed RIP boosts the data conversion performance. The main unit features a color management tool to reduce the time required to adjust colors for image reproducibility, while printing sharp text and numbers.

The printer will be for the first time presented to the public by Fuji Xerox at the IGAS trade show in Japan in September 2011.

New inkjet digital printer for the textile industry

A new high-performance inkjet digital printer for textiles has been developed as an alternative to flatbed screen printing. It is innovative economically and ecologically, since it reduces water and power consumption compared with conventional methods and at the same time offers total flexibility for customers. With printing speed of more than 600 sqm/hour (over 300 running meters) and excellent printing quality (1056 x 600 dpi), Durst Kappa 180 represents new upgraded product in textile printing sector.

The printer has been developed on the basis of Quadro printhead technology with the aim of meeting specific requirements of the textile industry. Specially developed high-grade inks are used for printing on different textile substrates. Three different varieties of ecofriendly inks are available for different substrates - reactive dyes for cotton and cotton mixtures with more than 60% cotton, dispersion dyes for synthetic fibers, polyester and polyester mixtures with more than 50% polyester and acid dyes for silk and silk mixtures. This technology enables eight color reproduction in CMYK, orange, red, blue and gray, with no modulations or density fluctuations. Ink delivery system with osmosis filtering system eliminates the tiny gas bubbles in the inks and ensures continuous and failure free printing.

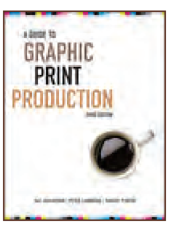
Bookshelf

A Guide to Graphic Print Production

Print production requires designers be familiar with graphic design, typography, illustration, editing, workflow management, materials, proofing, mechanical and photographic outputs, prepress processing, paper, color, manufacturing and distribution.

A Guide to Graphic Print Production covers all steps in the print production process with detailed explanations supported by informative sidebars and full-color illustrations.

The new third edition - expected in October 2011 - is fully updated to reflect all aspects of digital printing and the most current technologies. New and improved information covered includes variable data printing, sustainability, large/wide format printing, inks and color management.



A Guide to Graphic Print Production
Authors: Kaj Johansson, Peter Lundberg
and Robert Ryberg
Publisher: Willey Knowledge for Generations
ISBN 978-0-470-90792-4
400 pages
Hardcover

The Visual Dictionary of Pre-Press and Production

This handbook is a comprehensive guide to over 250 terms relating to the preparation and production of print and digital media and thus an invaluable introduction to the practical aspects of design and printing.

Each of the given terms is explained and contextualized, with concise definitions accompanied by a variety of diagrams, color illustrations and examples.

The book covers a range of practical processes as well as a variety of styles and finishes. It includes traditional terms still in current usage as well as modern terminology, from *Woodblock* to *Acrobat*. It also explains a range of practical processes, including *Accents*, *Bitmap* and *Colour calibration*, as well as styles and finishes, such as *Perfect bound*, *Totally chlorine free (TCF)* and *Offset lithography*.

The Visual Dictionary of Pre-Press and Production
Authors: Gavin Ambrose and Paul Harris
Publisher: AVA Academia
ISBN 978-2-940-41129-0
304 pages
250 color images
160mm x 120mm
Paperback

Designing Sustainable Packaging

Scott Boylston

Laurence King Publishing
ISBN 978-1-85669-597-8
400 illustrations
192 pages
Paperback

The book challenges the next generation of designers to re-envision packaging design in a more environmentally responsible way, and examines an array of techniques and methodologies for creating innovative and sustainable packaging designs, from first concept to final production.

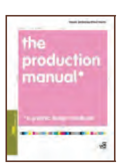
The book is organized into two distinct sections embracing first the theory, and then the practice of eco-friendly packaging design. In the first part of the book, after introducing the student to the background of packaging design and its purpose, the author focuses on issues of sustainability. Through a series of case studies and interviews he looks at some of the companies that are leading the way in sustainable packaging. The second part of the book provides practical information on creating eco-friendly packaging and follows various projects through, step by step.

The Production Manual

A Graphic Design Handbook

Gavin Ambrose and Paul Harris

AVA Academia Publishers
ISBN 978-2-940373-63-5
192 pages
200 color images
300mm x 220mm
Paperback



The book provides readers with the practical expertise necessary to print and produce creative work.

It allows graphic designers to apply the acquired knowledge. Essential production methods are covered in detail, with clear descriptions of the various technical processes involved in design for print, packaging etc.

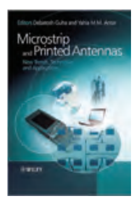
The book tackles issues such as image resolution, printing techniques and platemaking and demonstrates how to achieve difficult effects such as duotones and halftones. The text is supported throughout by examples of work taken from the best of contemporary design.

Microstrip and Printed Antennas:

New Trends, Techniques and Applications

This book focuses on new techniques, analysis, applications and future trends of microstrip and printed antenna technologies, with particular emphasis to recent advances from the last decade.

Attention is given to fundamental concepts and techniques, their practical applications and the future scope of developments. Several topics, essayed as individual chapters include reconfigurable antenna, ultra-wideband (UWB) antenna, reflect arrays, antennas for RFID systems and also those for body area networks. Also included are antennas using metamaterials. Essential aspects including advanced design, analysis and optimization techniques based on the recent developments have also been addressed. This book provides a reference for R&D researchers, professors, practicing engineers, and scientists working in these fields.



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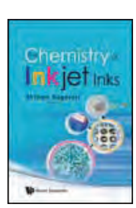
Hardcover

The Chemistry of Inkjet Inks

Modern printing is based on digitizing information and then representing it on a substrate, such as paper, pixel by pixel. One of the most common methods of digital printing is through inkjet printers. The process is very complicated and the ink used must meet certain chemical and physicochemical requirements including wetting and adhesion on substrates. Obviously, these requirements - which represent different scientific disciplines such as colloid chemistry and physics - indicate the need for an interdisciplinary book that will cover all aspects of making and utilizing inkjet inks.

This book provides basic and essential information on the important parameters which determine ink performance. It covers not only the conventional use of inkjet technology on graphic applications, but also the extension of this method to print various functional materials, such as the use of conductive inks to print light-emitting diodes (LEDs) and three-dimensional structures. Thus, the book will serve a large community: chemical engineers and physicists who deal with the rheological and flow properties of inks and researchers in academic institutes who seek to develop novel applications based on inkjet printing of new materials.



The Chemistry of Inkjet Inks
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Events

A global forum for innovations

One of the most expected events in the year 2012 will attract around 2 000 exhibitors and 350 000 visitors from all over the world. The event will certainly provide a lot of new ideas, innovations, applications, new solutions and strategies in all fields related with the printing industry. It will take place from 3 to 16 May, 2012 in Düsseldorf, Germany.

The main idea of drupa 2012 is to provide the connection between the content, technology and business models and not merely to focus on the technical innovations. This traditional trade show will therefore introduce a number of new features. The main focus of drupa innovation park 2012 (dip), presented by digi:media, will be on impulse-generating innovations in digital printing and media industry.

The basic concept of digi:media - bringing together all the target groups involved in workflow - will be supplemented with drupacube, the forum for the communication sector and customers. Thoughtful proximity of both events enables strong combination of technology and contents. Interactions between visitors and exhibitors as well as the exhibitors themselves will be much more efficient.

The drupa innovation park will occupy over 3 000 square meters of exhibition space and will be structured in nine exhibition segments. Chosen topics will be based on dynamic developments and trends in the print and media industry and its environment. Sections will cover different fields - process optimization and the greatest possible efficiency in the print process aided by planning systems, shop-floor management systems and MIS systems working (*Print Automation Park*); applications for mobile devices (mobile tagging), QR codes and augmented reality solutions for the future of print in combination with mobile communication (*Print meets Mobile Park*); strategies and solutions for multichannel publishing, applications for print and web, Web-to-Print, Print-to-Web, Print-on-Demand (*Dynamic Publishing Park*); innovations for sustainable print production (*Green Printing Park*); innovative print products, from print finishing solutions to secure printing (*Print Product Innovation Park*); tools for targeted communication (*Marketing Solutions Park*); innovations for the world of digital images (*Digital Imaging Park)* print in process (*Printed Electronics/Functional Printing Park*).

drupa 2012 will also host the Strategic networking meeting to be organized on 10 May 2012 in cooperation with iarigai. The SNM will bring together the scientists involved in the research for the printing industry, as well as companies and end users.

4th iarigai Strategic networking meeting

Understanding and developing the value chain in print production

Printing science meets the business

Düsseldorf, Germany
10 May 2012

The traditional annual Strategic networking meeting of iarigai will take place during drupa 2012 and hosted and co-organized by Messe Düsseldorf as the principal partner. It is intended to better understanding and cooperation between all participants in the value chain, thus creating an effective and sustainable framework for further development within the sector.

Some of the following topics will be specially emphasized:

- ◊ Introducing new research initiatives
- ◊ Recent industrial development
- ◊ Involving industry in the research
- ◊ Identification of end users' needs and expectations
- ◊ Integrating electronics with print
- ◊ Research associations as a driving force in networking of business and research
- ◊ Make better use of the research efforts and results
- ◊ The role of public funding in linking the research with the industry

GraphExpo

Chichago, Illinois, USA
11 to 14 September 2011

The greatest trade show on the North American continent will again attract many printers, suppliers and experts in the field.

Besides an impressive floor-show, numerous educational programs will feature a customized educational experience with value that can be utilized immediately. These sessions are created by industry experts to prepare the attendees with the latest forecast, in-depth information and trends on key technologies, essential business strategies and action-oriented solutions.

IC Conference

Norrköping, Sweden
19 to 23 September 2011

IC - the International Circle of Educational Institutes for Graphic Arts, Technology and Management is an informal network with approximately one hundred members from different parts of the world. The main focus of IC is the field of the graphic arts industry and the electronic media. Members of IC provide scientific, engineering, and economic education which qualifies their students for leading positions in the media industries. This network of different educational institutes organizes annual conferences, smaller events and issues a scientific journal.

This this year's 43rd annual IC conference will be hosted by the Institute of Technology, Linköping University Campus Norrköping. Conference will cover the fields of graphic arts technology, management and communication in a wider sense.

WCPC Annual Technical Conference

Swansea, UK, 7 and 8 November 2011

WCPC is a world renowned research centre dedicated to advancing the understanding and productivity of printing and coating. WCPC enhances the understanding of the printing and coating processes, exploits novel manufacturing using printing and applies its scientific findings to the benefit of its global industrial partners.

This 7th annual technical conference provides a unique opportunity to view the latest WCPC research in printing technology, to discuss the findings with researchers and to network with like minded industrial delegates. Each presentation will be a technical paper based on latest results and analysis derived from controlled experiments and numerical models. All attendees receive printed copies of the abstracts and a CD containing slides for each of the papers presented. Delegates will also have the opportunity to network at the conference dinner and visit the WCPC laboratories.

The conference will be held on the Swansea University campus in the Civil and Computational Conference room.

Traditional annual event

39th International research conference

Ljubljana, Slovenia, 9 to 12 September, 2012

Continuing almost 50 years of tradition, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries (iarigai) announces the 39th International Research Conference under the general heading - Advances in Printing and Media Technology. This traditional annual event will take place in Ljubljana, Slovenia from 9 to 12 September, 2012 and will be hosted by the University of Ljubljana - Faculty of Natural Sciences and Engineering, Department of Textiles.

The conference, entitled *Graphic communication and beyond*, will appeal to numerous participants from all over the world. It will be dedicated to the traditional print media, packaging, printed functionality, interactive communication including convergence of graphic communication with electronics, digital, interactive and other new media communication. The main goal of the conference is exchange of knowledge and presentation of research results of most interesting common research projects in the field and to open discussion on the challenges in and beyond the field of graphic communication. Special attention will be given to the following topics:

- Color science and technology
- Packaging as communicator and container
- Printed functionality
- Information design and visualization
- Interactivity in print and media
- Future of graphic communication

Faculty of Natural Sciences and Engineering is an active member of iarigai since 2004. Ljubljana is the political and cultural heart of Slovenia. It is considered a city that suits both its residents and many visitors. Even though it is a middle-sized European city, it maintains the friendliness of a small town and simultaneously possesses the characteristics of a metropolis. Here, at the meeting point of the cultures of east and west the old comes together in harmony with the new. Ljubljana also takes pride in its image as a green city. It is a very unique city, dotted with pleasant picturesque places, taking pride in its image as a green city. Ljubljana is a city of culture, hosting numerous theatres, museums and galleries and boasting one of the oldest philharmonic orchestras in the world.

Given its geographical position and short distances between places in Slovenia, Ljubljana presents a perfect base for exploring the country´s diverse features and beauty. Within a single day you can visit the Slovenian coast and high Alpine regions and experience different climates.

Call for submissions, important dates as well as other related information can be accessed at http://www.iarigai-ljubljana.org/.

Technical conference on deinking of digital prints

Grenoble, France, 8 and 9 November 2011

Constant development of digital printing encouraged CTP-Centre Technique du Papier in collaboration with Grenoble-INP Pagora to organize this year's Grenoble technical conference on deinking of digital prints in Grenoble on 8 and 9 November, 2011.

The aim of the conference is to review the latest progress in ink/paper interactions in the context of digital printing, with the attention on deinkability and deinking strategies. The chosen topics are therefore focused on paper technology for digital printing, digital printing technology, the current status and trends in deinking, deinking chemistry applied to digital prints prints, ink/paper interaction fundamentals (limited to digital prints), ink-jet inks and toners, paper impact on dienkability, environmenttal aspect of digital printing and simulation of deinking process and test methods/models.

The conference is expected to be an attractive and interesting event for all who are working in the field of recycling, deinking and digital printing, environmental issues and ink and paper industries.

More information about the program: http://pagora.grenoble-inp.fr.

X. Seminar in graphic arts

Pardubice, Czech Republic
19 to 21 September 2011

The Department of Graphic Arts and Photophysics of the University of Pardubice will host the X. international Seminar in graphic arts which will be held from 19 to 21 September, 2011 in the University Hall of Arnošt in Pardubice, Czech Republic.

The event will give an opportunity of combining scientific knowledge in printing technologies, materials, methods and processes of university researchers and industry specialists. Program topics are focused on the new application fields for printed products, research and development in print quality evaluation, advances in substrates and inks, trends in printing and finishing technologies and equipment and information and control systems for printing industry.

The seminar is divided in two parts. The first day (19 September) is dedicated to expert lectures on selected topics (color management, integration of digital printing to workflow of printing companies with conventional technologies, quality control, etc.) and will be held in Czech language. The objective is to offer various views, practical experiences and discussion with specialists. The second part of the event (20 and 21 September) will include oral and poster presentations of research results by international authors and will be given completely in English.

Three in one

World newspaper week

Vienna, Austria, 10 to 15 October 2011

IFRA Expo, the leading event of the news publishing and media industries is returning to Vienna in 2011: this time in combination with the 63rd World Newspaper Congress, the 18th World Editors Forum. The result is a mega event for the international news publishing industry that offers to the visitors, exhibitors or representatives of the trade press, networking at the highest level, much inspiration and a high use value.

A number of side actions will be organized along with the principal events: four Focus sessions on different topics, study tours, workshops, tutorials etc. After the successful première in 2010, the Media Port will be offered to participants, with top-class program of lectures presenting examples of international publishing practice.

The World Association of Newspapers and News Publishers or WAN-IFRA, is the global organization of the world's press, with more than 18 000 publications, 15 000 online sites and over 3 000 companies in more than 120 countries. With its wide array of conferences, training, seminars and research reports, WAN-IFRA is covering every aspect of newspaper production and news publishing. Its events and publications provide information on strategic and management issues, on editorial matters, on improving print quality and efficiency and much more.

IGAS2011

International Graphic Arts Show
Tokyo, Japan, 16 to 21 September 2011

The purpose of the International Graphic Arts Show (IGAS) is to develop and invigorate the graphic arts industries. Besides exhibiting cutting-edge products, displayed on over 41 000 sqm at the Tokyo Big Site exhibition centre, IGAS provides visitors with opportunities to study solutions for various current issues, to look for future technologies and to identify trends in printing and paper-converting technologies. The show will also facilitate international contacts for personnel in the printing and graphic industries.

Labelexpo Europe

Brussels, Belgium
28 September to 1 October 2011

Labelexpo Europe will introduce two new major feature areas at this year's show, taking place 28 September to 1 October 2012 at Brussels Expo. The exhibition is already larger than the previous edition and organizers are expecting that all six halls will sell out completely. This will make the show the largest ever label event.

For the first time at any Labelexpo show, there will also be a new feature dedicated to package printing. The Package Printing Zone will consist of seminar sessions and working machinery demonstrations. The aim of this feature is to introduce label printers to opportunities in short-run package printing (including flexible packaging, folding cartons, pouches and sachets). Many of these jobs can be printed on narrow to mid web presses and there will be package printing presses on display at the show.

TAGA 64th Annual Technical Conference

Jacksonville, Florida, USA
March 18-21, 2012

TAGA 's annual technical conference is an international event for the graphic arts that features technical papers on research straight from the laboratory, studies from the pressroom, software and systems engineering papers.

TAGA 's agenda delivers value to pressroom management, paper and ink specialists, prepress, micro technology, graphic arts educators, and research and development. The scope of the conference encompasses topics such as color management, materials, packaging, curing, process control, data management, workflow, security, MEMS, nanotechnology, printed electronics and fundamental science. Contributions that include the innovative application or evaluation of technology in the graphic arts are also encouraged.

The association also provides support to active student chapters around the world, TAGA's Annual Technical Conference provides students opportunities to participate in several competitions.

Seeking for a higher quality of the event, the submissions will be reviewed and consequently published in the *Scientific Papers of the University of Pardubice.*

For the third time, the seminar will be held under the auspices of iarigai, which is supporting the events of its active member organizations.

More information are available from http://sga.upce.cz.

4th International Student Conference

Printing Future Days 2011

Chemnitz, Germany, 7 to 10 November 2011

Young people, committed to the research have a seldom opportunity to present their results on big international conferences. The Department of Print and Media Technology of the University of Technology in Chemnitz decided therefore in 2005 to begin with a series of international conferences under the title *Printing Future Days*, primarily intended for young researchers. Throughout the years, these conferences developed into attractive events for the international audience.

The Printing Future Days 2011 will traditionally take place in Chemnitz, Germany, under the title 4th International Scientific Conference on Print and Media Technology. In four days, from 7 to 10 November 2011, participants will have an opportunity to present themselves to the universities and industry as well as to companies representatives. The conference is namely organized for young researchers, students and PhD students from universities throughout the world with the aim to provide a platform to experience, giving a talk for international experts in printing technology and to establish contacts for their carrier planning, either in science or industry.

This year's topics will cover the fields of digital and hybrid printing (engineering & development), mass-printing technologies (engineering & development), functional printing (smart objects, flexible electronics, power sources, …), packaging printing, inks and substrates and new media and business concepts.

Number of different and interesting topics will assure a remarkable event for all participants. The International Association of Research Organizations for the Information, Media and Graphic Arts Industries (iarigai), recognizing the efforts of pm-TUC in promoting the research of new generations - gladly continues supporting the Printing Future Days. The authors of the best reviewed contribution will be awarded with an invitation of presenting their paper in next iarigai conference, to be held in Ljubljana, Slovenia in September 2012.

More information about Printing Future Days 2011 is available at www.printingfuturedays.com.

Guidelines for authors

Authors are encouraged to submit complete, original and previously unpublished scientific or technical research works, which are not under review in any other journals and/or conferences. Significantly expanded and updated versions of conference presentations may also be considered for publication. In addition, the journal will publish reviews as well as opinions and reflections in a special section.

Submissions for the journal are accepted at any time. Papers will be considered for publishing if meeting the general criteria and ethic standards of the scientific publication. When preparing a manuscript for JPMRT, please strictly comply with the journal guidelines, as well as with the ethic aspects. The Editorial Board retains the right to reject without comment or explanation manuscripts that are not prepared in accordance with these guidelines and/or if the appropriate level required for scientific publishing cannot be attained.

A - General

The text should be cohesive, logically organized, and thus easy to follow by someone with common knowledge in the field. Do not include information that is not relevant to your research question(s) stated in the introduction.

Only contributions submitted in English will be considered for publication. If English is not your native language, please arrange for the text to be reviewed by a technical editor with skills in English and scientific communication.. Maintain a consistent style with regard to spelling (either UK or US English, but never both), punctuation, nomenclature, symbols etc. Make sure that you are using proper English scientific terms.

Do not copy substantial parts of your previous publications and do not submit the same manuscript to more than one journal at a time. Clearly distinguish your original results and ideas from those of other authors and from your earlier publications - provide citations whenever relevant. For more details on ethics in scientific publication, please consult: http://www.elsevier.com/ethicalguidelines.

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B - Structure of the manuscript

Title: Should be concise and unambiguous, and must reflect the contents of the article. Information given in the title does not need to be repeated in the abstract (as they are always published jointly).

List of authors: i.e. all persons who contributed substantially to study planning, experimental work, data collection or interpretation of results and wrote or critically revised the manuscript and approved its final version. Enter full names (first and last), followed by the present address, as well as the e-mail addresses.

Separately enter complete details of the corresponding author - full mailing address, telephone and fax numbers, and e-mail. Editors will communicate only with the corresponding author.

The title of the paper and the list of authors should be entered on a separate cover page (numbered as 0). Neither the title nor the names of authors can be mentioned on the first or any other following page.

Abstract: Should not exceed 500 words. Briefly explain why you conducted the research (background), what question(s) you answer (objectives), how you performed the research (methods), what you found (results: major data, relationships), and your interpretation and main consequences of your findings (discussion, conclusions). The abstract must reflect the content of the article, including all keywords, as for most readers it will be the major source of information about your research. Make sure that all the information given in the abstract also appears in the main body of the article.

Keywords: Include three to seven relevant scientific terms that are not mentioned in the title. Keep the keywords specific. Avoid more general and/or descriptive terms, unless your research has strong interdisciplinary significance.

Abstract and keywords should be entered on a separate page, numbered as page 1. Do not continue with the main body of the text, regardless of the empty space left on this page.

Introduction and background: Explain why it was necessary to carry out the research and the specific research question(s) you will answer. Start from more general issues and gradually focus on your research question(s). Describe relevant earlier research in the area and how your work is related to this.

Methods: Describe in detail how the research was carried out (e.g. study area, data collection, criteria, origin of analyzed material, sample size, number of measurements, equipment, data analysis, statistical methods and software used). All factors that could have affected the results need to be considered. Make sure that you comply with the ethical standards, with respect to the environmental protection, other authors and their published works, etc.

Results: Present the new results of your research (previously published data should not be included). All tables and figures must be mentioned in the main body of the article, in the order in which they appear. Do not fabricate or distort any data, and do not exclude any important data; similarly, do not manipulate images to make a false impression on readers.

Discussion: Answer your research questions (stated at the end of the introduction) and compare your new results with published data, as objectively as possible. Discuss their limitations and highlight your main findings. At the end of Discussion or in a separate section, emphasize your major conclusions, pointing out scientific contribution and the practical significance of your study.

Conclusions: The main conclusions emerging from the study should be briefly presented or listed, with the reference to the aims of the research and/or questions mentioned in the Introduction and elaborated in the Discussion.

Introduction, Methods, Results, Discussion and Conclusions - as the scientific content of the paper - represent the main body of the text. Start numbering of these sections with page 2 and continue without interruption until the end of Conclusions. Number the sections titles consecutively as 1, 2, 3 … while subsections should be hierarchically numbered as 2.1, 2.3, 3.4 etc. Use Arabic numerals only.

Note: *Some papers might require different structure of the scientific content. In such cases, however, it is necessary to clearly name and mark the appropriate sections.*

Acknowledgments: Place any acknowledgements at the end of your manuscript, after conclusions and before the list of literature references.

References: The list of sources referred to in the text should be collected in alphabetical order on a separate page at the end of the paper. Make sure that you have provided sources for all important information extracted from other publications. References should be given only to documents which any reader can reasonably be expected to be able to find in the open literature or on the web, The number of cited works should not be excessive - do not give many similar examples. Responsibility for the accuracy of bibliographic citations lies entirely with the authors.

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List of symbols and/or abbreviations: If non-common symbols or abbreviations are used in the text, you can add a list with explanations. In the running text, each abbreviation should be explained the first time it occurs.

Appendix: If an additional material is required for better understanding of the text, it can be presented in the form of one or more appendices. They should be identified as A, B, etc. instead of Arabic numerals.

Above sections are supplementary, though integral parts of the Scientific content of the paper. Each of them should be entered on a separate page. Continue page numbering after Conclusions.

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For technical requirement related to your submission, i.e. page layout, formatting of the text, as well of graphic objects (images, charts, tables etc.) please see detailed instructions at http://www.iarigai.org/publications/journal.

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Before sending your paper, check once again that it corresponds to the requirements explicated above, with special regard to the ethic issues, structure of the paper as well as formatting. Once completed, send your paper as an attachment to: **journal@iarigai.org**. You will be acknowledged on the receipt within 48 hours, along with the code under which your submission will be processed. The editors will check the manuscript and inform you whether it has to be updated regarding the structure and formatting. The corrected manuscript is expected within 15 days.

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Printing and publishing of papers once accepted by the Editorial Board will be carried out at the earliest possible convenience.

1-2012

Journal of Print and Media Technology Research

A peer-reviewed quarterly

The journal is publishing contributions in the following fields of research:

- Printing technology and related processes
- Premedia technology and processes
- Emerging media and future trends
- Social impacts

For details see the Mission statement inside

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