J. Print Media Technol. Res.
Vol. IV – No. 1 (1–80)
March 2015

ISSN 2223-8905
CODEN JPMTBI
UDC 665

1-2015

Journal of Print and Media Technology Research

Scientific contents

Professional communications

9772223890003

Editor-in-Chief Gorazd Golob (Ljubljana)

Published by iarigai The International Association of Research Organizations for the Information, Media and Graphic Arts Industries

www.iarigai.org

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4(2015)1, 1–80
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Journal of Print and Media Technology Research

A peer-reviewed quarterly

PUBLISHED BY

The International Association of Research Organizations for the Information, Media and Graphic Arts Industries

Magdalenenstrasse 2, D-64288 Darmstadt, Germany

http://www.iarigai.org E-mail: journal@iarigai.org

A mission statement

To meet the need for a high quality scientific publishing in its research fields of interest, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries (iarigai) publishes the peer reviewed quarterly Journal of Print and Media Technology Research.

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By regularly publishing peer-reviewed high quality research articles, position papers, survey and case studies, the Journal will consistently promote original research, networking, international collaboration and the exchange of ideas and know how. Editors will also consider for publication review articles, topical and professional communications, as well as opinions and reflections of interest to the readers. The Journal will also provide multidisciplinary discussion on research issues within the field and on the effects of new scientific and technical development on society, industry and the individual. Thus, it will serve the entire research community, as well as the global graphic arts and media industry.

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Journal of Print and Media Technology Research

1-2015

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J. Print Media Technol. Res. 4(2015)1, 1–80

Journal of Print and Media Technology Research is listed in:

Index Copernicus International

PiraBase and PaperBase (by Smithers Pira)

NSD – Norwegian Register for

Scientific Journals, Series and Publishers

Printed in Slovenia by Birografika BORI, d. o. o. Ljubljana

Contents

First letter from the new Editor

Gorazd Golob
Editor-in-Chief

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Welcome to the first issue of the Journal of Print and Media Technology Research created by the new Editorial team. It should be pointed out that it is a transitional issue, as all of the published articles have already been sent in 2014 and the review and editing was done in cooperation with the former Editor-in-Chief Nils Enlund, Executive Editor Mladen Lovreček and other members of the team, who all deserve credit for their contribution to the Journal in the first three years of its existence. On this occasion I would also like to thank them for their trust, as well as for the help and support with publishing this issue of the Journal. I strongly believe that the reinforced Editorial team and the Scientific Advisory Board will continue with their support in this transitional period and in the future.

By taking over the duties of Editor-in-Chief, I accepted the obligation to continue the excellent work of my predecessors. Our goal is for the Journal of Print and Media Technology Research to be considered as the basic form of communication in the interested academic and professional community. I believe we will succeed, with proper support of the interested community of researchers and scientists in the field of printing and media technology, as well as with the support of the editorial board, reviewers, authors and all others who are interested in the publishing of the key Journal in a newly establishing scientific and research field.

My first insights and experience show that we need to work primarily on increasing the prevalence and visibility of the journal. User-friendliness to the authors should be significantly improved by shortening the reviewing and editing time, while maintaining the established high standards of peer-review and editorial process. The contents of the published papers will remain interdisciplinary, covering a wide range of topics, including the traditional print and new interactive media communication, the social impact of modern media, the use of printing technology in the field of printed electronics, color reproduction, typography, graphic design, packaging and any other advances in related fields.

The journal will also retain the Topicalities section where readers are informed about news and innovations, newly issued publications, textbooks, successfully defended doctoral thesis in our field and important events and activities. This section is edited by Markéta Držková, Associated Editor, who more than successfully continues the work of her predecessors Raša Urbas and Mladen Lovreček. Our intention is that this part of the Journal becomes the key media for communication between academic, research and other advanced and ambitious institutions, researchers and professionals from around the world. Of course, this can only be done with strong community support, therefore you are all invited to join us by providing news from your institutions and research fields, reviews of new publications and other contributions that could be of interest to your colleagues.

With the new website, which will be online soon, the Journal will be able to follow modern trends in communication and become a key connection point for the mutual exchange of information between the members of our publisher, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries – iarigai, and other interested members of the academic, research and professional community.

You and your colleagues are kindly invited to submit papers reporting the highest achievements of your research work, as well as other contributions. We will be happy to increase the volume of the Journal or publish the issues more frequently, should the need arise.

The process of "changing of the guard" as my predecessor Nils Enlund aptly named the transfer of the duty and responsibility to the new editorial team is finished with this first issue in Vol. IV. During editing I have come to new insights, as well as some ideas on how to improve the impact and image of the magazine. Much depends on us who create the Journal, along with our publisher – iarigai, who is kindly supporting our activities. We are all looking forward to following the road to success, recognition and visibility. The criteria for the assessment of our success will be mainly in the quality and number of published papers and their impact on our academic and research community.

Ljubljana, March 2015

JPMTR 053 | 1413
DOI 10.14622/JPMTR-1413
UDC 6551 : 532.6-035

Research paper
Received: 2014-07-15
Accepted: 2014-11-28

Inkjet printed hydrophobic microfluidic channelling on porous substrates

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Abstract

Paperfluidic devices consist of patterned microfluidic channels formed on paper or paper-like material. The direction of surface and bulk liquid flow is typically controlled by patterning hydrophobic barriers on the otherwise hydrophilic paper substrate. A variety of hydrophobic materials and functional printing methods can be used for the patterning. Unlike conventional graphical printing, hydrophobising ink must penetrate the whole depth of the substrate to form an effective barrier against leakage from the channel. This study focuses on the development of solvent-based hydrophobic inks for inkjet printing of microfluidic patterning. Hydrophobic inks were produced by dissolving alkyl ketene dimer (AKD) and polystyrene (PS) in p-xylene. Hydrophobic test patterns were inkjet printed with these inks on two highly porous filter papers. The AKD-based ink was found to produce effective hydrophobic barriers but suffered from poorly defined borders. The PS-based ink produced well defined borders, but could only penetrate the full depth of the substrate on one of the chosen papers. Adding PS to AKD ink improved jettability. Hydrophobic ink penetration into filter paper was found to take place as surface film flow over the skeletal fibre structure of the paper. Therefore, paper fibre surface properties and ink surface tension and viscosity are considered to play controlling roles in determining the penetration depth. Differences seen with respect to aqueous wicking behaviour at the interface/border between hydrophilic and hydrophobic regions might be due to the Marangoni derived coffee stain effect and likely to interactions with the fibre surfaces.

Keywords: functional printing, hydrophobic ink, polystyrene, alkyl ketene dimer, paperfluidics

1. Introduction and background

Paperfluidic devices are being developed as a low cost application for functional microfluidics in the field of lab-on-a-chip devices, intended to provide simple, transportable, disposable and self-sufficient analytical tools for a variety of applications including medical diagnostics and environmental monitoring. On such devices, designed for aqueous liquids, samples flow along hydrophilic channels through or to assay zones, where they chemically interact with pre-applied reagents. Results of such reactions can then be analysed visually based on colour, or by external instrumentation, to obtain information on the contents of the test samples (Ballerini, Li and Shen, 2012; Liana et al., 2012).

Based on their design, paperfluidic devices can be divided into three categories of dimensional constructions, i.e., 1D, 2D and 3D devices. In 1D devices, such as commercially available early pregnancy tests, liquid is carried only in a single direction (Dharmaraja et al., 2013). In 2D devices, first introduced in 2007, aqueous liquid flows along channels created by patterning hydrophobic barriers onto an otherwise hydrophilic base substrate (Martinez et al., 2007). This provides room for more complicated assays and for multiple assays on a single device. 3D devices are produced by layering multiple 2D devices on top of each other, allowing liquid to flow both within the layers and from one layer to another (Martinez, Phillips and Whitesides, 2008).

A variety of hydrophobic materials and printing methods have been recently demonstrated as feasible ways of producing hydrophobic patterns on highly permeable filter or chromatography papers. The most prevalent of these methods is inkjet printing, demonstrated with hot-melt wax (Carrilho, Martinez and Whitesides, 2009), solvent-diluted polydimethylsiloxane (Määttänen et al., 2011), UV-polymerising materials (Maejima et al., 2013), acrylic polymer in solvent-based solution (Apilux et al., 2013) and paper sizing agents in solvent-based solution (Li, Tian and Shen, 2010) as well as in the form of aqueous emulsions (Wang et al., 2014; Xu and Enomae, 2014). Other printing methods typically demonstrated include flexographic printing of solvent-based polystyrene ink (Olkkonen, Lehtinen and Erho, 2011) and screen-printing of candle-making wax (Dungchai, Chailapakul and Henry, 2011).

Unlike conventional graphical printing, in patterning paperfluidic devices hydrophobising ink has not only to cover the surface but also penetrate the whole depth of the hydrophilic substrate in order to produce properly functioning barriers without leaks (Ballerini, Li and Shen, 2012). This full depth penetration can be assisted by having ready wetting of the substrate by the ink, low ink viscosity, high substrate permeability or large volume of applied ink. Wax-printed substrates, for example, are heated after printing to melt the wax and make it penetrate into the pores.

This study, based in part on a thesis work (Koivunen, 2014), focuses on the development of simple low cost solvent-based hydrophobic inks for inkjet printing of microfluidic patterning on porous paper substrates. For this purpose, two different hydrophobising agents, polystyrene (PS) and alkyl ketene dimer (AKD – a paper sizing agent), were used to manufacture inks, both on their own and combined. So far, studies published about hydrophobising agents have usually reported results for only a single material in isolation, with only one published study comparing multiple hydrophobising agents, specifically wax, AKD and methylsilsesquioxane (Wang et al., 2014). Also, no known studies to date have combined multiple hydrophobising materials into a single ink.

Various aspects of these inks and their interaction with substrates were studied. Firstly, the physical ink properties and jettability were characterised. Secondly, physical pattern dimensions achievable by different ink, substrate and print setting combinations were studied. Thirdly, functionality and reliability of the printed patterns in directing flow of aqueous liquid were tested.

Jettability of inkjet inks can be characterised by the inverse Ohnesorge number Z (Jang, Kim and Moon, 2009), a dimensionless number defined as

$$Z = \frac{1}{Oh} \qquad [1]$$

where

$$Oh = \frac{\sqrt{We}}{Re} = \frac{\eta}{\sqrt{a \varrho_{\mathrm{ink}} \gamma}} \qquad [2]$$

in which Re stands for the Reynolds number, We the Weber number, a the characteristic dimension over which flow occurs (the nozzle radius), ϱ_{ink} the ink density, γ the ink surface tension and η the ink viscosity. A good jettability range for Newtonian liquids has been proposed to be $4 < Z < 14$ (Jang, Kim and Moon, 2009), with fluids of higher values of Z exhibiting satellite droplet formation, while those with lower values of Z require excessively long periods of time for the connecting filament to break free from the nozzle, or possibly do not jet at all.

Inkjet printing of solvents containing PS in solution has been reported previously (de Gans et al., 2004; Hoath, Hutchings and Martin, 2009), with molecular weight demonstrated to have a significant effect on jettability due to non-Newtonian rheological behaviour of polymer containing solutions in the print head. However, this viscoelastic behaviour has no significant effect on drop impact or spreading, at least in the case of a non-porous substrate (Jung, Hoath and Hutchings, 2013). High molecular weight polymers can also be liable to degradation by central scission in the print head (A-Alamry et al., 2011).

The feasibility of using PS-containing ink for hydrophobic patterning of paper has, to our knowledge, only been studied once in the literature, using flexographic printing as the patterning method (Olkkonen, Lehtinen and Erho, 2011). In that study, printing had to be carried out on both sides of a substrate, since insufficient depth coverage was achieved with single-sided printing. Another known method involving PS is etching of hydrophilic channels with pure solvent using inkjet printing onto a sheet of paper that has been impregnated beforehand with PS (Abe, Suzuki and Citterio, 2008). However, this method requires up to ten sequential printings to re-deposit enough PS from the channels to their edges, making it a rather slow procedure in practice.

AKD, chosen as a reference material in this study, has previously been successfully inkjet printed to produce paperfluidic devices (Li, Tian and Shen, 2010; Wang et al., 2014). Alternatively, AKD impregnated paper has been patterned by using selective plasma treatment to return areas of paper back to the hydrophilic state (Li et al., 2008). AKD is a paper sizing agent that reacts with hydroxyl groups on the cellulose surface, replacing them with hydrophobic β-keto ester groups.

Physical resolution and functional dimensions reported for paperfluidic patterning methods usually include minimum widths for reliably working barriers and channels. Barriers are those hydrophobic structures separating hydrophilic sections, and the minimum width (nominal or measured) indicates the pattern width required to achieve reliable full depth coverage. Channels are hydrophilic areas limited by the barriers, where liquid will flow in a controlled fashion. Minimum channel width indicates the mean channel width where liquid will still flow reliably, and, with channels narrower than this, irregularities in barrier edge definition will start to block the channel.

2. Materials and methods

2.1 Inks

The chosen hydrophobising agents used in this study were 35 kDa molecular weight polystyrene (Sigma-Aldrich, product code 331651) and solid alkyl ketene dimer Basoplast 88 (BASF). These were dissolved in p-xylene solvent (Acros Organics or Fluka) to produce the hydrophobising inks. This solvent has a viscosity of 0.648 mPa s and the surface tension 28.37 $mN\,m^{-1}$ at 20 ºC, making it suitable for the printer used in this study. Furthermore, p-xylene has been previously shown to be a suitable solvent for PS ink printed with flexography (Olkkonen, Lehtinen and Erho, 2011).

Three inks were produced, with the first one containing 5 % by weight PS, the second one containing 6 % by weight AKD and the third one containing 2 % by weight PS and 6 % by weight AKD. These inks will be henceforth referred to as PS, AKD and AKD-PS inks, respectively. During the study, a total of 5 batches of PS ink, 2 batches of AKD ink and 1 batch of AKD-PS ink were produced.

Cyan and magenta dyes in water were used to visualise hydrophilic regions. The cyan dye solution consisted of 0.2 % by weight concentration of nickel(II) phthalocyanine-tetrasulphonic acid tetrasodium salt (Sigma-Aldrich), supplied as dry powder, dissolved in distilled water. The magenta dye solution consisted of 10 % by weight concentration of commercial carmine food colorant (Dr. Oetker), provided as a highly concentrated aqueous solution, diluted accordingly with distilled water.

2.2 Substrates

Two different commercial filter papers, Whatman grades 1 and 4 (GE Healthcare), manufactured from cotton cellulose, were selected as test substrates for printing. Information about technical properties of these substrates, as provided by the manufacturer, is listed in Table 1.

The porosity ε of each substrate was determined by calculation from the thickness dimension of the sheet and the physical parameters of the paper constituents, namely using Equation 3

$$\varepsilon = 1 - \frac{b}{h\varrho_{\text{solid}}} \qquad [3]$$

where b is the basis weight, h the thickness of the sheet and ϱ_{solid} the density of the solid phase. For cellulose, ϱ_{solid} reported in literature is 1 540 $kg\,dm^{-3}$ (Koivula et al., 2013).

Table 1: Substrate properties

Substrate	Whatman 1	Whatman 4
Thickness (µm)	180	205
Basis weight ($g\,m^{-2}$)	88	96
Particle retention under filtration (µm)	11	20–25
Air flow permeability ($s/100\,cm^3/in^2$)	10.5	3.7
Porosity (%)	68	70

2.3 Equipment

Ink surface tension was measured with a CAM200 contact angle measurement system (KSV) using the pendant drop method in a laboratory room maintained at 23 ºC. Ink viscosity was determined using an MCR-300 rheometer (Paar-Physica) with a PP50 flat disc spindle and a P-PTD 150 Peltier temperature controlled base plate. Viscosity measurements were conducted at a shear rate of 100 s^{-1} and with the Peltier base plate set at 30 ºC.

The inks were printed with a Dimatix material printer DMP-2831 (Fujifilm Dimatix), using the manufacturer's DMC-11610 ink cartridges with nominal 10 pl drop volume. Jettability of the inks was studied using the integrated drop watcher camera, observing drop velocity and satellite droplet formation as functions of drive voltage and jetting frequency, which were increased in 1 V and 2 kHz intervals, respectively.

For image analysis, printed samples were scanned with an Epson Expression 1680 scanner (Seiko Epson) and analysed with ImageJ software version 1.44p (National Institute of Health) to calculate the dimensions of printed barriers and channels. The software functionality setting "Analyze particles" was used to measure the area of a scanned section of channel or barrier. The area was then divided by the length of the scanned section to obtain mean width.

2.4 Print settings and post-print treatment

The inks were printed from the print head, set to 30 °C, onto the substrates held by vacuum on the mounting platen, set to 28 °C. The drive waveform "high viscosity short polymer" provided on the Dimatix device was used in all cases, as it was seen to provide the best jetting. Patterns were printed with a variety of drop spacing values, ranging from 10 to 50 µm (equivalent to 2 590 to 518 dpi).

Prints containing only dissolved PS were ready to use immediately after the solvent had evaporated. The AKD containing prints required curing in an oven or on a laboratory hot plate at 100 °C for 10 minutes to ensure that the AKD had reacted properly with the substrate cellulose.

2.5 Test patterns

Due to the recent introduction of 2D paperfluidics, no standard method exists yet for evaluating properties of printed hydrophilic channels and hydrophobic barriers on porous substrates. Therefore, a test method was developed for this study, strongly inspired by prior examples in the literature (Carrilho, Martinez and Whitesides, 2009). For this method, three different test patterns ("lines", "channels" and "barriers") were created, using the pattern editing software provided with the printer, and printed on the test substrates with the designed inks. The printed patterns were effectively invisible when dry, but became visible when wetted, as demonstrated in Figure 1. This is due to an opacity change in hydrophilic regions as pores are filled with water.

Figure 1: Wetting causes a visible opacity change in the hydrophilic areas; displayed here are two Aalto University logotypes printed with PS ink, shown dry (left) and after dipping in water (right)

For testing how the printed patterns affect liquid transport, cyan dyed water was allowed to wick up along the hydrophilic regions from the bottom edge of the printed samples. For this purpose, the test prints were suspended vertically in jars containing dyed water at the bottom, as demonstrated in Figure 2. By using dyed rather than clear water, the results could be more easily observed during testing and also analysed later on when the samples were dry.

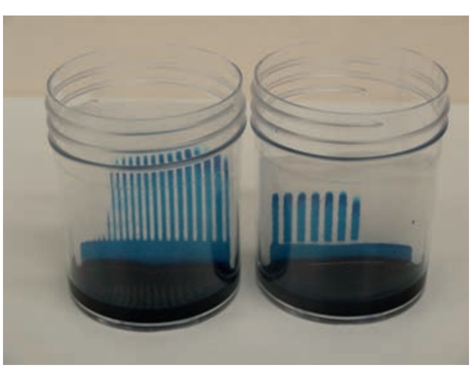

Figure 2: Experimental set-ups for testing channels (left) and barriers (right); cyan coloration indicates areas where water has wicked

The first pattern ("*lines*"), designed to measure line spreading, featured ten 35 mm long straight lines. These varied in nominal width from 0.1 to 1.0 mm in 0.1 mm increments. Cyan dyed water was allowed to wick up the channel until it fully surrounded the top of the lines, after which the samples were dried and scanned to determine actual line widths on the printed and reverse (non-printed) sides.

The second pattern ("*channels*"), designed to measure working channel widths, shown in Figure 3, featured 22 hydrophilic channels 32 mm long and of varying nominal widths, from 0.5 to 2.6 mm in 0.1 mm increments. Cyan dyed water was allowed to wick up the channels for 5 minutes, after which the test samples were dried and scanned to determine actual channel widths. The samples were also examined to determine the narrowest channel where the liquid could travel the full length of the channel within the given time.

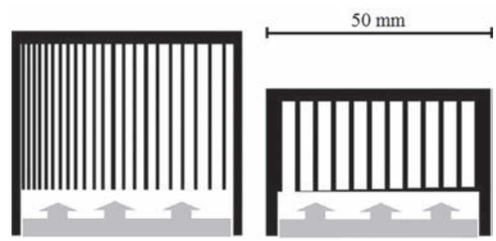

Figure 3: Test patterns for channels (left) and barriers (right); black indicates the hydrophobic region, white the hydrophilic region, with light grey indicating the original exposure to an effectively unlimited source of dyed water as well as the direction of subsequent wicking

The third pattern ("*barriers*"), designed to measure barrier widths required to contain liquid, also shown in Figure 3, featured ten hydrophilic channels with barrier structures of varying widths printed across them, as well as one control channel without any barrier. For samples printed with PS containing ink, the barriers ranged in nominal width from 0.1 to 1.0 mm in 0.1 mm increments. For samples printed with AKD containing inks, nominal barrier widths ranged from 0.05 to 0.50 mm in 0.05 mm increments. Dyed water was allowed to try to wick past the barriers for 30 min, with samples observed every 5 minutes to determine which of the barriers had been penetrated. After this, magenta dyed water was added to the channels that had not been penetrated, followed by drying and scanning of the test devices to determine the actual width of the non-penetrated barriers on the printed side.

Studied sample sizes for given ink/substrate/drop spacing combinations were 5 samples for lines, 10 samples for channels and 10 samples for barriers. For a barrier to be considered reliable, it needed to resist penetration on all 10 tested samples. Similarly, for a channel to be considered reliable, it needed to transport liquid properly on all 10 tested samples.

3. Results

3.1 Ink properties and jettability

The physical properties of the inks, measured from a single batch per ink, are listed in Table 2. Values for Z have been calculated according to Equation 1, with a nozzle radius, a, of 10.5 µm. The reported viscosity values were measured at the relatively low shear rate of 100 s^{-1}, which is not representative of the high shear rates to be found within the print head, but partly reflects the close to static viscoelasticity, i.e., the viscoelasticity existing under small applied strain contributes to the apparent shear viscosity at low shear. All of the inks tested also displayed shear thickening when tested over the shear rate range of 100 to 1 000 s^{-1}, but the available instrumentation, limited to small volumes, did not provide the possibility to test viscous behaviour at shear rates beyond this shear thickening region.

Table 2: Ink properties

Ink	Ink content	Viscosity at 30 °C (mPa s)	Surface tension at 23 °C (mN m^{-1})	Z
PS	PS (5 %)	1.21 ± 0.07	28.18 ± 0.15	13.2
AKD	AKD (6 %)	0.63 ± 0.04	28.54 ± 0.21	25.5
AKD-PS	PS (2 %) and AKD (6 %)	0.90 ± 0.04	28.35 ± 0.12	17.8

Jettability tests showed that the PS ink was jettable up to 10 kHz, though 6 kHz provided more stable performance. The AKD ink was only jettable at 2 kHz, while the AKD-PS ink was jettable up to 6 kHz. At higher frequencies than these, jetting tended to become unstable, easily resulting in nozzle plate flooding. The actual printing frequency was set at 2 kHz for the AKD ink and 6 kHz for the PS and AKD-PS inks.

Drop velocities during jetting have been observed to increase approximately linearly as a function of the jetting voltage (Hoath et al., 2013). In the present study, the PS and AKD-PS inks behaved in this fashion. However, with the AKD ink the velocity peaked at 8 m s^{-1} and could not be increased beyond this level by further increases in jetting voltage. However, this velocity was still within the recommended velocity range of 5–10 m s^{-1} for the printer. Based on drop velocity studies, the drive voltages for the inks for actual printing were set at 18 V for AKD ink, 16 V for AKD-PS ink and 28 V for PS ink, resulting in jetting velocities in the 8–9 m s^{-1} range.

Satellite droplets were observed for all inks under all tested jetting conditions, and could not be fully eliminated in this study. This is not particularly surprising, considering the high values of Z for the inks, resulting from their low viscosities.

3.2 Line spreading

On the printed side, significant line spreading could be observed for all of the inks. On the reverse (non-printed) side, the lines on some samples are slightly narrower than on the printed side, and in some cases they were discontinuous, indicating that the printed ink had achieved full depth coverage only locally. The well-defined and continuous lines tended to have widths of at least 500 µm, with narrower lines displaying discontinuity.

Closer drop spacing, resulting in a higher volume of ink being applied for a given nominal line width, resulted in greater line spreading. Widening the nominal line width resulted in slightly reduced relative line spreading. Some examples of the relative line width for PS and AKD inks as a function of nominal line width are shown in Figure 4.

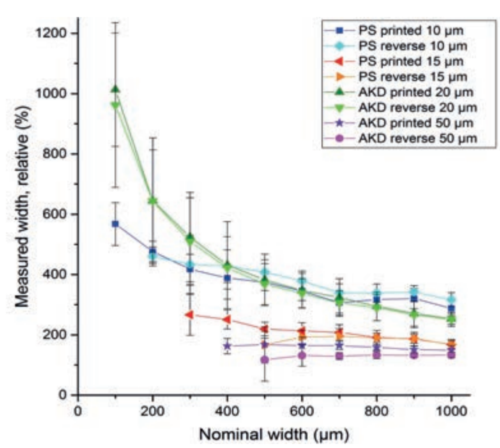

Figure 4: Relative line widths, in terms of nominal width, for Whatman 4 filter paper printed with PS ink at 10 and 15 µm drop spacing, and with AKD ink at 20 and 50 µm drop spacing

The AKD and AKD-PS inks exhibited roughly similar line spreading. The PS ink could not be directly compared with the others, due to PS ink requiring a drop spacing of 15 µm or less for full depth coverage. Trying to print the same test pattern with AKD or AKD-PS inks with such a close drop spacing resulted in some of the lines merging with their neighbours, so that widths of all lines could no longer be measured.

3.3 Hydrophobic barriers

Barrier penetration was observed at 5 min intervals for 30 min. For most of the barriers that were penetrated this happened within the initial 5 minutes, with usually only a small portion of barriers being penetrated after that. An exception to this was PS ink on Whatman 1, where a higher level of barrier penetration could be observed after the initial 5 min period.

For a given barrier to be considered reliable, it needed to be able to resist penetration for the entire 30 min period on 10 samples tested in parallel. The PS ink could only produce reliable barriers on Whatman 4 filter paper, and only with a drop spacing of 10 or 15 µm. With a 15 µm drop spacing, reliable barriers could be produced by printing barriers with a nominal width of 400 µm, resulting in actual barriers with a measured width of 883 ± 91 µm, while for 10 µm drop spacing, a nominal barrier 300 µm wide was required resulting in a measured barrier width of 996 ± 114 µm. Examples of printed barrier patterns after testing are shown in Figure 5, where cyan dyed channels indicate ones where coloured water wicked past the barrier while magenta dyed channels indicate ones where the barrier was not penetrated.

When PS ink was used with a drop spacing of 20 µm or more, or with Whatman 1 filter paper, full depth coverage could no longer be achieved. Instead, the reverse side of the printed patterns remained partially hydrophilic, allowing liquid to leak past. This is easily observable on the reverse side of the samples, as shown in Figure 6, where the liquid, having penetrated the initial barrier is not fully contained by the channel beyond but starts to spread further. This difference in depth coverage is not due to the thickness of the sheet, since Whatman 1 is actually slightly thinner than Whatman 4.

AKD and AKD-PS inks could produce reliable barriers on both Whatman 1 and Whatman 4 filter papers with all tested drop spacing values (up to 50 µm). The measured widths for the narrowest reliable barriers for these inks with different print settings are shown in Figure 7. Required nominal line widths for these barriers ranged from 50 to 450 µm, increasing as drop spacing increased. Notice, that for a number of these samples printed with close drop spacing, line spreading of the channel walls constricted the channel beyond the barrier so much that measuring the actual barrier width reliably was no longer possible.

As can be seen from Figure 7, there are no clear relationships between barrier width and drop spacing, paper type or ink type. Reliable barriers could be produced with a variety of settings for these inks as long as the nominal line width would be set large enough to ensure that a continuous barrier was formed on the reverse side.

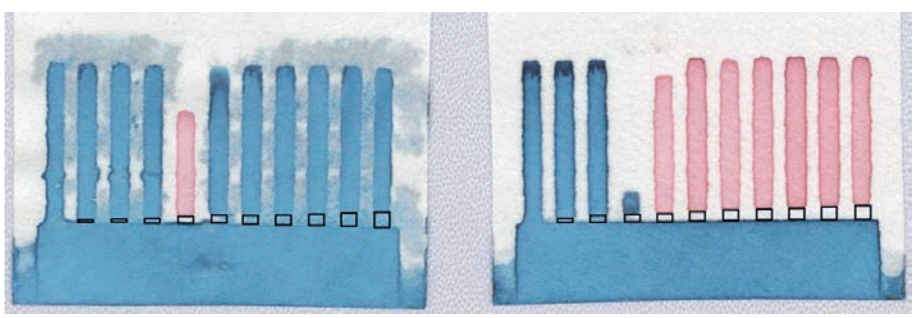

Figure 5: Examples of barrier tests, printed with PS ink at drop spacing of 15 µm on Whatman 1 (left) and Whatman 4 (right) filter papers; for clarity, printed barriers have been outlined with rectangles

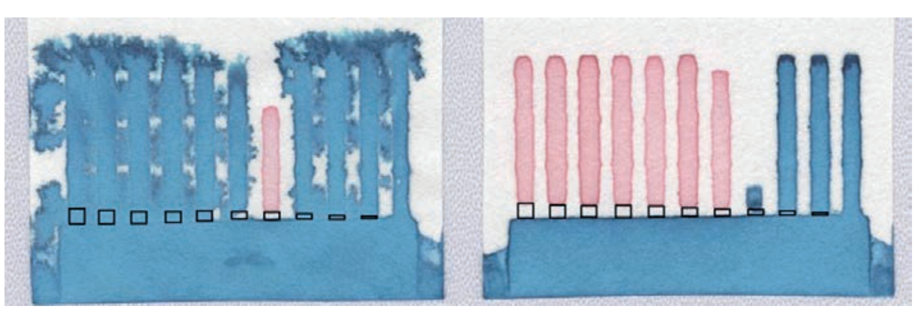

Figure 6: Reverse side views of the samples shown in Figure 5; on Whatman 1 (left), significant liquid spreading on the reverse side can be observed; barriers have been outlined with rectangles, as in Figure 5

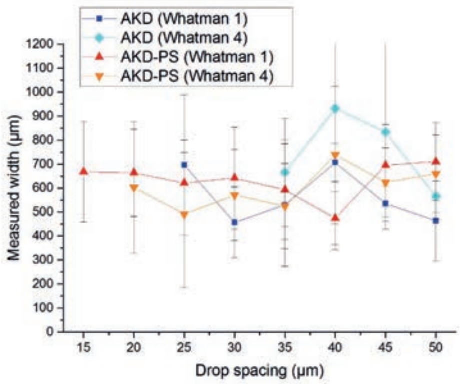

Figure 7: Measured widths of reliable barriers printed with AKD and AKD-PS inks

3.4 Hydrophilic channels

For producing narrow, fast wicking channels, the PS ink performed well. Using Whatman 4 filter paper and 15 µm drop spacing, channels down to a measured width of 680 ± 80 µm on the printed side could be produced, with dyed water consistently wicking a 30 mm distance along a channel within 5 minutes on all 10 samples. The nominal width of these channels was 1 300 µm, with the difference being due to line spreading of the surrounding barriers.

With AKD and AKD-PS inks, no fast-wicking channels could be produced. Rather, the water in the channels travelled so slowly that it could not even reach the top of the channel when the observation time was extended to 10 minutes. Close observation of these channels during tests indicated that the liquid front did not travel the whole width of the channel, unlike with channels printed with PS ink. Instead, the liquid wicked initially along the middle of the channel and then spread slowly to the sides of the channel. Even on the post dried sample, as shown in Figure 8, the wedge-shaped wicking front can be observed. The wider the channel, the longer the wicking front would advance within the given time.

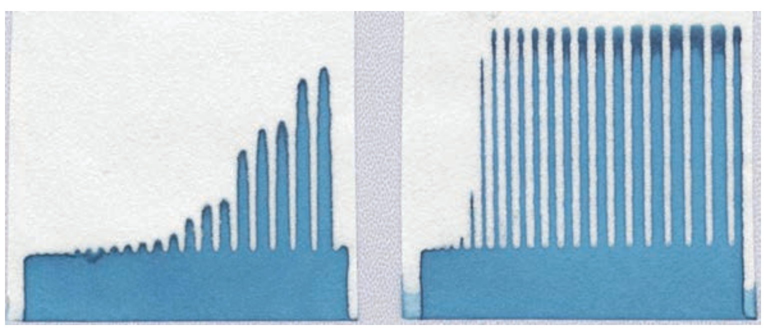

Figure 8. Examples of channel tests, printed on Whatman 4 filter paper with AKD ink at a drop spacing of 45 µm (left) and with PS ink at a drop spacing of 15 µm (right)

4. Discussion

4.1 Ink and substrate properties

In the light of the observations made in the previous section, the following commentary on correlations between the applied parameters of the inks, printing and substrates is offered.

All three inks could be jetted successfully. However, plain AKD ink featured limited jetting performance, being restricted to 2 kHz jetting and displaying velocity peaking. This is likely due to the low viscosity of the AKD ink, being very close to that of pure solvent. Adding a small amount of PS as a rheological modifier to produce AKD-PS ink resulted in a slight positive increase in low shear viscosity and, consequently, a significant improvement in jettability. This viscosity-related improvement in jettability might be partially due to a resulting viscoelastic behaviour leading to a temporary elastic response while under high stress in the print head. While strongly viscoelastic behaviour, such as exhibited by solutions containing high molecular weight polymers, can limit jettability (de Gans et al., 2004), a low level of viscoelasticity might actually improve jettability of otherwise low viscosity solutions. However, in this study the actual viscoelasticity of the inks was not measured.

The PS ink could achieve reliable full depth penetration on Whatman 4 filter paper, but not on Whatman 1, indicating that there is a significant substrate property difference between these two papers. It cannot be due to thickness, as Whatman 4 is actually the thicker of the two. Both papers are also reported to contain fibres of effectively the same dimension (Evans et al., 2014). Whatman 4, however, has significantly higher air permeability, which could suggest a correlation, though as gas and liquid may travel in quite different fashions through a substrate, this might not apply to all substrates.

Nevertheless, the path travelled by liquid through the sheet was presumably more tortuous in Whatman 1.

The AKD ink proved to be superior in depth penetration. This is at least partly due to the lower viscosity of the AKD ink, not only when jetted initially on paper, but also during the spreading and drying period when liquid viscosity increases due to solvent evaporation. However, the penetration might be further aided by the curing step, where the AKD is heated well above its melting point of ca. 50 ºC, providing it with an opportunity to spread slightly further than where it was initially deposited during drying. Adding some PS to AKD ink did not have any significant effect on this spreading behaviour.

The PS ink produced patterns with sharply defined edges, suggesting that there was a sufficient amount of PS on the edges of the printed patterns to produce clear contrast between the untreated and hydrophobised regions. Actually, there was some indication that the PS concentrations might actually be slightly higher at the edges of the printed patterns, which could be a result from the "coffee stain" phenomenon, where dry solids contained within a drying drop are deposited at the edges, most likely by Marangoni flow. However, this would require further characterisation before it could be confirmed.

On the other hand, with AKD and AKD-PS inks the edge regions were poorly defined, containing a semi-hydrophobised border area where water could advance slowly. This border area resulted in slowly wicking channels, as the central part of the channel also needed to feed these areas on the sides. This poor edge definition could be caused by affinity between AKD and fibre surfaces, leading to partial separation of AKD from the ink as it spreads, and resulting in only small amounts of AKD being deposited at the edges. Again, further studies would need to be performed to characterise this behaviour more fully.

4.2 Ink volume versus pore volume

Information provided by the line spreading tests can be used to calculate the effectively hydrophobised pore volume, V_{hpores}, for a section of a hydrophobic barrier. In parallel, the actual ink volume, V_{ink}, consumed to print the same section can be calculated from the print settings. For the following analysis, we choose this barrier section to consist of a single transverse line of printed drops.

We can consider this transverse line across a barrier to consist of a number of printed dots, N, defined by the drop spacing distance, d, and the nominal print setting width of the barrier, w_n, and given by Equation 4.

$$N = w_n / d \qquad [4]$$

The N drops, therefore, deliver the volume of ink, V_{ink}, across the barrier width (Equation 5),

$$V_{ink} = NV_{drop} \qquad [5]$$

where V_{drop} is the volume of ink jetted in a single drop.

As an aside, we can also determine the available pore volume V_{pores} that is present underneath this line of drops, assuming perfect merging of the drops on the surface (Equation 6),

$$V_{pores} = Nd^2h\varepsilon \qquad [6]$$

where, as before, d is the drop spacing, N the number of drops, h the substrate thickness and ε its fractional porosity. This available pore volume is, however, not necessarily saturated with ink, depending on the flow properties of the ink inside the substrate structure, and so we need to consider the realistic situation of diminishing contacted volume as the ink penetrates.

If we assume that the penetration of the ink reaches the complete thickness, as required for a satisfactory barrier, and that the cross-sectional penetrated profile is, in a first approximation, that of a wedge, as shown schematically in Figure 9, we may determine the effectively hydrophobised pore volume V_{hpores} underneath the printed transverse line by Equation 7,

$$V_{hpores} = d\left(\frac{w_p + w_r}{2}\right)h\varepsilon \qquad [7]$$

defining w_p as the transverse line length (width) of the barrier on the printed side and w_r the observed barrier width on the reverse side, created by penetration.

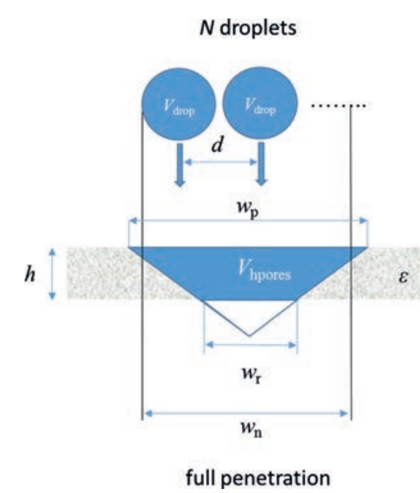

Figure 9: Schematic showing the applied drop volume V_{drop} with a drop spacing d, which is applied to the substrate of thickness h to form a nominal transverse barrier width w_n having a wedge-shaped cross-section of width w_p and w_r on the printed and reverse sides, respectively, such that the pore volume affected by the hydrophobising agent is V_{hpores}

The ratio V_{hpores}/V_{ink} informs us about the mechanism of ink distribution and its hydrophobising impact (Equation 8),

$$\frac{V_{hpores}}{V_{ink}} = \frac{V_{hpores}}{NV_{drop}} = \frac{d\left(\frac{w_p + w_r}{2}\right)h\varepsilon}{\left(\frac{w_n}{d}\right)V_{drop}} = \frac{d^2 h\varepsilon\,(w_p + w_r)}{2w_n V_{drop}} \qquad [8]$$

such that, when the volume of hydrophobised pores exceeds that of the applied volume of ink, $V_{hpores}/V_{ink} > 1$, we can assume that ink has penetrated, at least at the latter stages, by film flow without filling the total available pore volume.

Assuming that the drop volume V_{drop} is the nominal 10 pl and using substrate properties given in Table 1, V_{hpores}/V_{ink} values can be calculated for the lines printed in the present study. They are presented in Figure 10 for Whatman 4 filter paper. For Whatman 1, the calculated V_{hpores}/V_{ink} ratios are around 14 % lower.

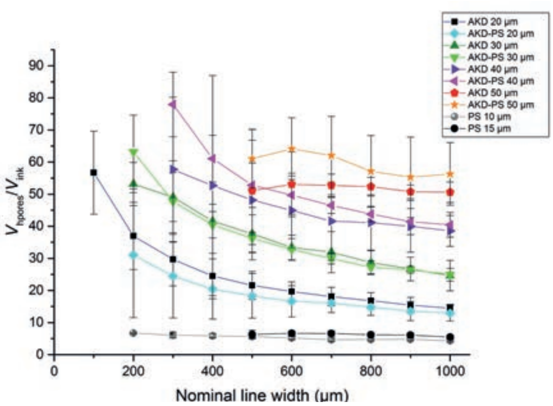

Figure 10. V_{hpores}/V_{ink} ratios for lines printed on Whatman 4 filter paper, as a function of nominal line width for a range of inks and drop spacing values

The values of V_{hpores}/V_{ink} vary quite a bit, from around 5 for PS ink to over 50 for AKD containing inks printed with large drop spacing. They are all significantly higher than 1, indicating that the hydrophobising ink does not completely fill the pore volume available beneath the applied ink. This confirms the suggestion that the ink spreading has primarily taken place through film flow on fibre surfaces, rather than through complete filling of the pores. Previously, the initial advance of the water front on un-sized paper has been demonstrated to be similarly controlled by the surface film flow (Roberts et al., 2003).

Also the pore filling level was studied separately by inkjet printing wax, heated to make it melt and penetrate the full depth of the filter paper, and considering the weight of the deposited wax into the substrate layer in relation to the mass that could have been filled into the total available pore volume. Hydrophobic barriers covering the full depth of the paper can be produced by a wax application that fills only 19 % of the paper pore volume (Wang et al., 2014). While not explicitly stated by the authors, these results indicate that melted wax must have spread primarily by surface film flow rather than by bulk flow within a saturated pore volume.

4.3 Comparison with previous studies

In a previous study, featuring PS as printed hydrophobising material, Olkkonen, Lehtinen and Erho (2011) tested chromatography paper (Whatman grade 1 Chr, thickness 180 µm, basis weight unspecified) and found that it could not be hydrophobised to a sufficient depth by applying a single flexographic printing on one side. Rather, each side needed to be printed, one side with the actual pattern and the reverse side with 100 % coverage. However, in the current study, PS could be successfully used to produce barriers with a single printing, provided that the substrate allows the ink to penetrate rapidly. This difference in performance may be attributed to both a higher volume of ink transferred by inkjet compared to flexography and to differences in ink viscosity due to ink composition. While both studies used xylene-based ink with 5 % by weight PS content, the current study uses PS with a lower molecular weight (35 kDa vs. 290 kDa) to aid mobility further, resulting in a significant difference in viscosity (1.2 vs. 6 mPa·s). Perhaps improved penetration depth using flexography could be achieved by using a lower viscosity PS solution as the ink. However, it is also possible that the demonstrated difference in performance might be due partially to the different substrates used.

AKD containing inks displayed poor edge definition of printed patterns, a property not reported in a previous study featuring AKD based ink printed on Whatman 4 filter paper (Li, Tian and Shen, 2010). This prior report used n-heptane as the solvent, which has higher vapour pressure and lower surface tension than p-xylene, resulting in reduced spreading on the substrate before drying. This may have resulted in less noticeable unevenness at the edges. The difference cannot have been due to substrate properties, since identical substrates were used in both studies.

The barrier and channel dimensions reported in this study for inkjet printed PS ink are in the same region as those previously reported for other printing methods and materials. The channel width of 680 ± 80 µm, as reported in the present study, matches the 700 µm channel width reported for inkjet printed PDMS on Whatman 1 filter paper (Määttänen et al., 2011), while being slightly wider than the 500 µm width reported for flexographically printed PS (Olkkonen, Lehtinen and Erho, 2011) and the 561 ± 45 µm width reported for inkjet printed hot-melt wax (Carrilho, Martinez and Whitesides, 2009). Similarly, the barrier width of

883 ± 91 μm is quite close to the 850 ± 50 μm width reported for inkjet printed hot-melt wax. Two-sided flexographic printing with PS ink could achieve narrower 400 μm wide barriers.

Perhaps resolution in the present study could have been improved by trying two sided printing, with the reverse side printed using 100 % coverage, but with a sufficiently sparse drop spacing of 20–25 μm to ensure that the ink printed on the reverse side does not penetrate the full depth of the substrate. This would result in the ink printed on the primary side having to penetrate to a lesser depth in order to produce reliable barriers. Thus narrower lines, penetrating less in depth but resulting in narrower barriers, could be printed.

5. Conclusions

PS containing solutions can be inkjet printed to provide well-defined hydrophobic patterning on porous substrates. However, the application window for the studied PS ink was rather narrow, requiring a suitable substrate for the PS ink to allow it to penetrate the full depth of the substrate.

The AKD ink was found to provide superior penetration and hydrophobising properties when compared to PS, although it suffered from limited jetting performance. The latter could be improved by adding some PS to the ink as a rheological modifier. However, patterns printed with AKD containing inks featured poor edge definition, not reported in previous studies.

Comparison of hydrophobised substrate pore volumes and printed ink volumes revealed that the printed ink volume could have filled only a small portion of the covered pore volume. This indicates that the ink spread primarily through film surface flow along fibre surfaces, rather than by complete filling of pores. It is expected that the inkjet technique and inks developed here could be further enhanced by better definition of the substrate structure, which is a topic for future work.

Acknowledgements

The alkyl ketene dimer sample used in this study was donated by Chemigate Oy. Funding for the project was provided by Omya International AG.

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JPMTR 054 | 1442
DOI 10.14622/JPMTR-1442
UDC 655 : 621.38

Research paper
Received: 2014-11-25
Accepted: 2015-02-13

Improving conductivity of rotary screen printed microparticle silver conductors using a roll-to-roll calendering process

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Abstract

A roll-to-roll (R2R) calendering process was developed and used to improve the conductivity of rotary screen printed microparticle silver conductors. Two commercial microparticle silver pastes were used. In the calendering process, the rotary screen printed microparticle silver conductors are compressed under pressure and heat in order to make the porous microparticle layer denser and flatter. The results show that the resistivity of the rotary screen printed microparticle silver conductors was dramatically dropped after the R2R calendering process by 29–56 % depending on the silver paste. The complete drying of the calendered conductor layer decreased the resistivity even further as a result of which the layer resistivity was decreased 74 % from its initial value. The roughness of the silver conductors was also reduced remarkably after the calendering by 45–72 %. The effect of the R2R calendering process on the printed inductively remote readable capacitive moisture sensor based on simple inductor-conductor resonant circuit was also demonstrated. Calendering improved the Q-factor of the sensor but decreased the resonance frequency.

Keywords: rotary screen printing, calendering, microparticle silver, printed conductor, roll-to-roll printing

1. Introduction

Printed large area electronics has been under very active research for past 10 years in various fields in passive (Allen et al., 2011b) – and active electronic (Park et al., 2012) –, optic (Mäkelä and Haatainen, 2012) – and optoelectronic components including organic photovoltaics (Sondergaard et al., 2012) and organic light emitting diodes (Kopola et al., 2009). Despite different printing processes, various other roll-to-roll (R2R) compatible pre- or post-treatment processes are often required to achieve the best performance of the printed electronic components in the R2R manufacturing environment. This is due to a fact that in order to achieve well printable inks they have to include different additives like functional fillers, binder resins, surfactants, wetting agents and/or different boiling point solvents. Typically these additives affect electrical or optoelectronic properties of the printed component. The additives must be removed in order to obtain most efficient component performance.

Conductors in case of electronic circuits play an important role when the performance of the electronic circuit is considered. Resistive losses should be minimized to avoid additional power losses in the circuitry. In addition, physical dimensions and surface properties of the conductors should be optimized in such a way that integration of other components and multilayer structures can be made effectively. Several different processes based on thermal annealing (Girotto et al., 2009), laser sintering (Ko et al., 2007), microwave (Perelaer, de Gans and Schubert, 2006) and electrical sintering (Allen et al., 2011a) as well as chemical (Magdassi et al., 2010) and plasma (Reinhold et al., 2009) sintering have been introduced to reduce the resistivity of the printed nanoparticle silver conductors. It has to be emphasized that these sintering processes work with nanoparticle inks since energy required to sinter nanoparticles is much less than with microparticle based inks.

Calendering is widely used in the common paper making industry to improve the printability of papers by modifying their surface properties. In calendering, the paper is run through one or several nips. The application of compression and heat makes the paper surface denser, smoother, glossier, and flatter. In addition, the texture of the calendering rolls, roll elasticity, and dwell time in the nip affect the final surface properties (Ehrola et al., 1999).

In this paper we introduce a R2R processing technique – calendering – to reduce the resistivity and surface roughness of rotary screen printed microparticle silver conductors. This technique has been previously used to improve the conductivity of printed conductive patterns (Nguyen et al., 2011; Joyce, Fleming and Prabhakar Pandkar, 2010). Recently also a novel pressure-annealing method for fabricating printed low-work-function metal patterns and printed metal alloy patterns was introduced (Yoshida et al., 2011). In addition, an inductively remote readable capacitive moisture sensor based on a simple inductor-capacitor (LC) circuit is manufactured utilizing the rotary screen and R2R calendering processes using real R2R pilot printing machines.

2. Materials and processes

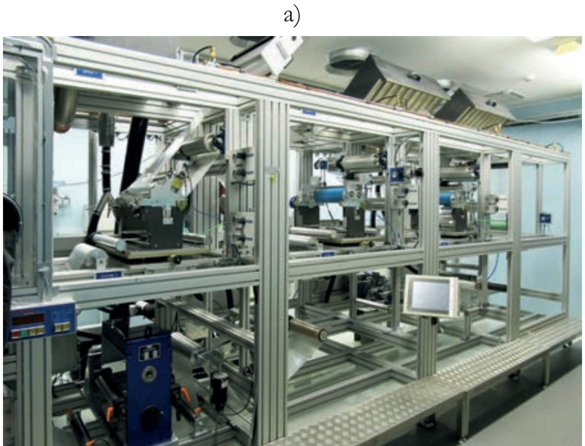
Two commercially available microparticle silver pastes, Asahi LS-411AW and Asahi LS-415C-M, were rotary screen printed with a pilot printing machine, shown in the Figure 1a), onto 125 μm thick and 250 mm wide OPET Lumirror 40.01 plastic foil by Toray. Both inks are one-component, polymer type, microparticle silver pastes whose main difference lies in the viscosity. The viscosities for LS-411AW and LS-415C-M inks are 20–30 Pa s and 30–40 Pa s, respectively. Gallus RVS cylindrical screen with a mesh count of 275 was used to print line patterns having different widths and a inductor-capacitor circuit structure (Figure 2). The inks were printed at a speed of 1 m/min and dried at 140 °C. The total dwell time in the ovens was approximately 4 min.

After the printing, the printed conductor layers were R2R calendered using a thermal nanoimprinting unit of second pilot printing machine, shown in Figure 1b). A smooth and blank nickel sleeve with an anti-adhesion coating was used instead of the imprinting sleeve since the surface texture of the calendering roller is copied onto the surface of the printed layer. The calendering conditions were first optimized with smaller sheets by using different nip pressures (10–15 bar), process speeds (0.5–1 m/min), and cylinder temperatures (110–130 °C). In order to maximize the calendering effects to the printed layers, merely low process speeds and high nip pressures and cylinder temperatures were tested. Finally, the R2R printed LS-411AW and LS-415C-M conductors were calendered in a R2R process using the optimized conditions.

Due to the fact that the conductor layer drying process was extremely short, 4 min, the effect of the complete drying of both printed and calendered layers on the layer properties was also studied. Some samples were dried offline in an oven at 150 °C for 30–60 min. As a result, residual solvents were completely removed.

The printed conductor layers were analysed both before and after the calendering process. The layer thickness and roughness was measured using Veeco Wyko white-light interferometer. In the case of roughness, both R_a (average roughness) and R_q (RMS roughness) values were reported. The ink spreading was measured by determining the line width after the printing and calendering processes with OGP SmartScope video measurement system and OGP MeasureMind metrology software.

a)



b)

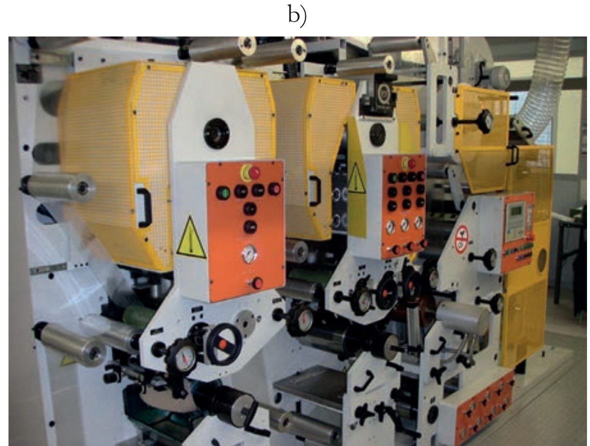


Figure 1: a) Pilot machine used for rotary screen printing of conductive micro-particle pastes and insulator materials; b) Pilot machine used for R2R calendering

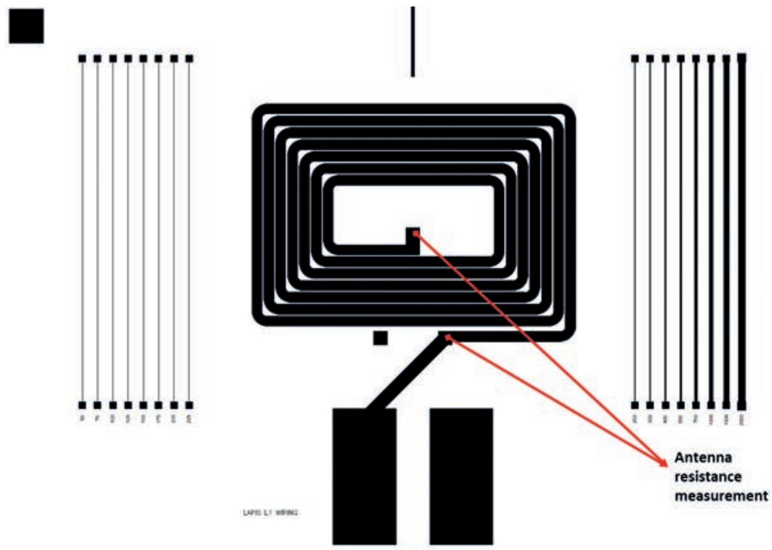


Figure 2: Printing layout containing lines with different widths and a LC-circuit structure in the middle; the resistance across the circuit was measured between the shown points

The layer conductance was determined by measuring the resistance across the antenna (shown in Figure 2 with arrows) and 500 µm wide lines. The volume resistivity (ϱ) of the printed and calendered layers was finally calculated using Equation 1

$$\varrho = RWh/L \quad [1]$$

where means of the line width (W), line length (L), layer thickness (h), and resistance across the line (R) were used.

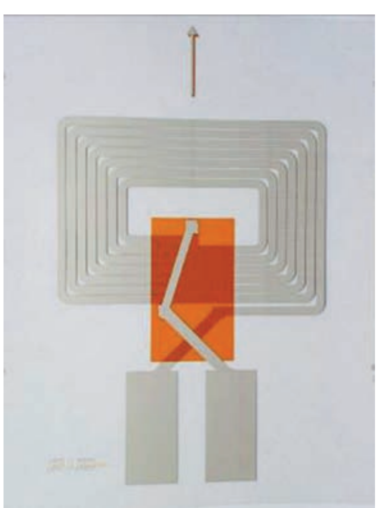


Figure 3: Printed moisture sensor with LC-circuit, dielectric, and wiring layers printed with ROKO printer at a speed of 1 m/min

Moisture sensors design (Hast et al., 2012), shown in Figure 3, was manufactured by screen printing insulator and wiring layers onto the printed LC-circuit. Asahi CR-18Y2-PI(CK) or Asahi CR-18G-KT1 insulators were screen printed onto the LC-circuits after which the wirings were deposited with Asahi LS-411AW silver paste. The two insulating pastes are both two-component type and have similar viscosity of 4–7 Pa s in addition to which their performance was found to be similar, thus making the LC-circuits comparable. Moisture sensors were rotary screen printed at a speed of 1 m/min onto un-calendered LC-circuits. The printed layers were dried at 140 °C and the dwell time in the ovens was 4 min. The insulator layer was printed using Gallus EP cylindrical screen with a mesh count of 110. The insulator layer thickness was 16.1 µm. The wirings were screen printed with Gallus RVS screen (mesh count of 275). In the case of calendered LC-circuits, sensors were printed using a flatbed screen printer and a mesh count of 325. Two layers of insulator were printed in order to obtain similar thickness as in the case of rotary screen printing. After that, the wiring layer was printed. The insulating layer thickness was 16.6 µm. The printed layers were dried in an oven at 140 °C for 4 min (comparable to the R2R process) or at 150 °C for 1 h (complete drying).

The moisture sensor performance was analysed at dry and moist conditions using a measurement setup shown in Figure 4a). Both quality factor (Q-factor) and resonance frequencies were determined using a digital oscilloscope measuring LC-circuit's impulse response and calculating Fast Fourier Transform (FFT) for the measured signal. Q-factor is determined as a ratio of the impulse response resonance frequency (f_0) to 3 dB band width of the impulse response FFT spectrum according to Equation 2. Figure 4b) illustrates definition of the Q-factor in frequency domain.

$$\text{Q-factor} = f_0/f_{3dB} \quad [2]$$

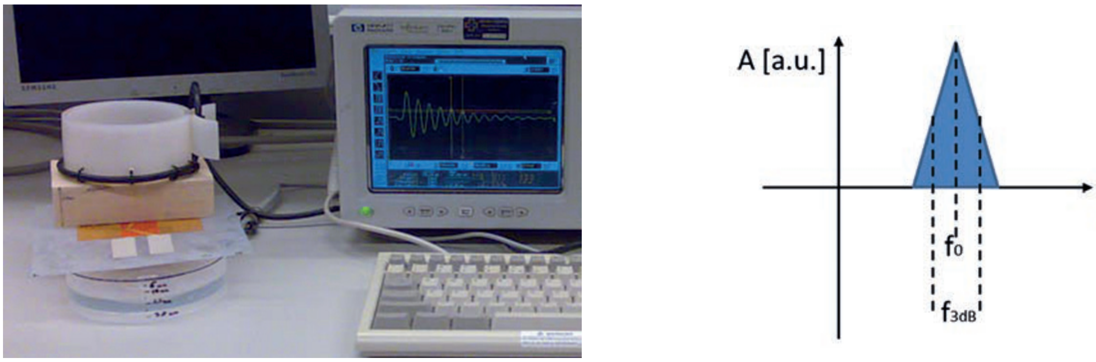


Figure 4: a) Measurement setup for the analysis of the resonance frequencies and Q-values of the printed sensors at moist and dry conditions; the sensor is separated from the water source by 4 cm thick dry Finnish pine wood; b) Definition of Q-factor in frequency domain

3. Results and discussion

3.1 Effect of calendering on the surface properties of the printed layer

The optimum R2R calendering conditions were first determined by feeding R2R printed sheets into the process. Figure 5 and Figure 6 show the results. Calendering increases the layer conductivity by making the layer smoother and denser. As a result, silver particles in the ink layer are compressed into more intimate contact with each other and the amount and size of empty spaces in the layer decrease. This allows less resistive current flow through the layer. The resistance across the antenna decreases 40–55 % during the calendering and the amount depends on the calendering conditions and ink type and printed layer properties.

The increase in the calendering nip pressure has no significant effect on the conductivity. This resulted from the limit of the nip pressure beyond which the ink layer cannot be compressed anymore. Furthermore, too high nip pressure can also cause damages to the printed layer or lead to the ink sticking onto the calendering sleeve. Therefore, the nip pressure level of 10 bar was chosen for the R2R calendering experiments.

As the calendering speed decreases from 1 m/min to 0.5 m/min, the dwell time of the ink layer in the nip under compression increases, thus fortifying the calendering effects to the printed layers. This leads to smoother, denser, more even, and more conductive layers. The conductivity of the ink layer increases approximately 5 %.

The increase in the calendering temperature by 10 °C also improves the layer conductivity by 10 %. The higher the calendering temperature, the softer and more easily deformable the ink layer gets. However, if the calendering temperature is increased excessively, binders in the ink become sticky. This leads to the fouling of the calendering sleeve and causes damages to the ink layer.

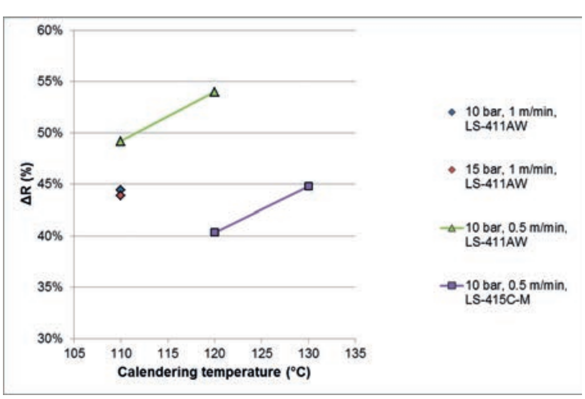


Figure 5: Antenna resistance changes ($\Delta R(\%) = (R_{initial} - R_{calandered})/R_{initial}$) of printed Asahi LS-411AW and LS-415C-M sheets during R2R calendering using different calendering temperatures, speeds, and pressures

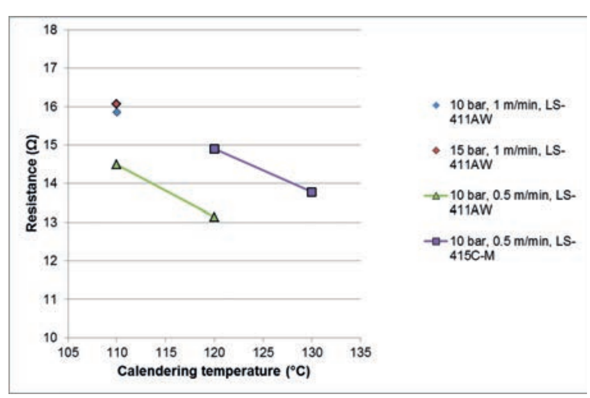


Figure 6: Resistance across the printed LC-circuit sheets after R2R calendering as a function of calendering temperature, speed, and pressure. Both Asahi LS-411AW and LS-415C-M inks are used

LS-415C-M ink layer does not respond to the calendering as well as LS-411AW ink. Un-calendered LS-415C-M ink layers are more conductive than LS-411AW ink layers but after calendering LS-411AW layers become more conductive. For example, calendering at 120 °C increases the conductivity by 54 % in the case of LS-411AW ink and only 40 % in the case of LS-415C-M ink.

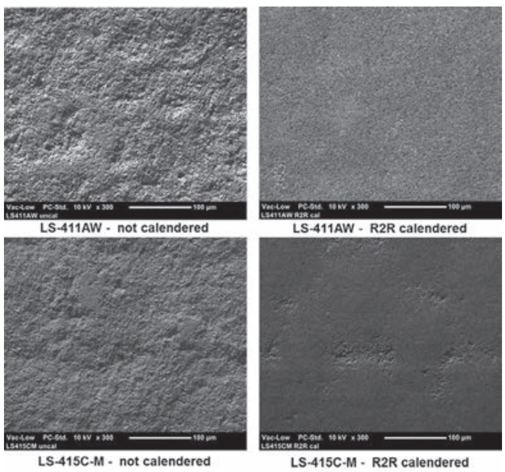


Figure 7: Effect of the ink type and R2R calendering on the surface properties of the conductor layer; images are taken with SEM using a magnification of ×300

The R2R calendering experiments were done for both conductor inks using a calendering speed of 0.5 m/min and temperature of 120 °C. In Figure 7, the effect of the R2R calendering on the layer topography is shown. The calendering process makes the printed layers significantly smoother and more uniform because of the heat and compression encountered in the nip. The irregularities of the ink layer surfaces disappear and the ink layer becomes denser, thus making better and more intimate particle-to-particle contacts. Initially, LS-415C-M conductor layer is smoother than LS-411AW conductor layer but after the calendering process the irregularities of the layer printed with LS-411AW ink have evened out better. Thus, LS-411AW ink layer is more conformable.

After printing LS-411AW ink layers are thicker and they spread more than LS-415C-M layers due to the lower viscosity of LS-411AW ink. The lower the viscosity, the more the ink is squeezed through the tiny holes of the screen, i.e. is transferred onto the substrate. At the same time, the ink spreading also increases. LS-415C-M ink produces also smoother layers than LS-411AW ink.

The thickness, roughness, and ink spreading changes during calendering are presented in Figure 8a, Figure 8b, and Table 1, respectively. The R2R calendering decreases the layer thickness and roughness, and slightly increases spreading. However, LS-415C-M ink layers do not respond to the calendering as well as LS-411AW ink layers because of the thinner layers and higher solids content of the ink. The thinner the layer, the less it can physically be compressed and deformed. In addition, the higher solids content decreases the amount of empty space in the ink layer, thus decreasing the layer response to the calendering.

In calendering, the printed layer is densified since empty spaces in the printed layer are removed and particles in the ink layer get into better contact with each other. This decreases the layer thickness by 21 % and 13 % in the case of LS-411AW and LS-415C-M inks, respectively. However, the ink spreading increases only 1–2 % during the calendering. This is caused by the fact that the ink layer entering the calendering process is almost dry and it is only softened in the nip. Therefore, the short dwell time in the nip is not enough to make the ink flow on the substrate.

Table 1: Spreading of Asahi LS-411AW and LS-415C-M inks during R2R calendering

Ink	Spreading of 500 µm lines (µm)	
	Before	After
LS-411AW	36	46
LS-415C-M	3	8

a) b)

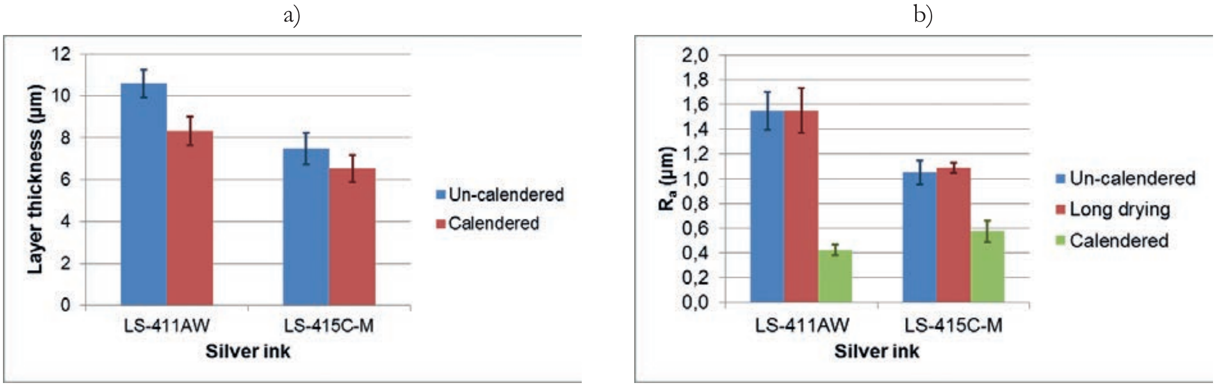


Figure 8: Effect of the calendering on the layer thickness (a) and average layer roughness (b) in the case of Asahi LS-411AW and Asahi LS-415C-M silver pastes; the effect of the further oven drying on the layer roughness is also presented

a) b)

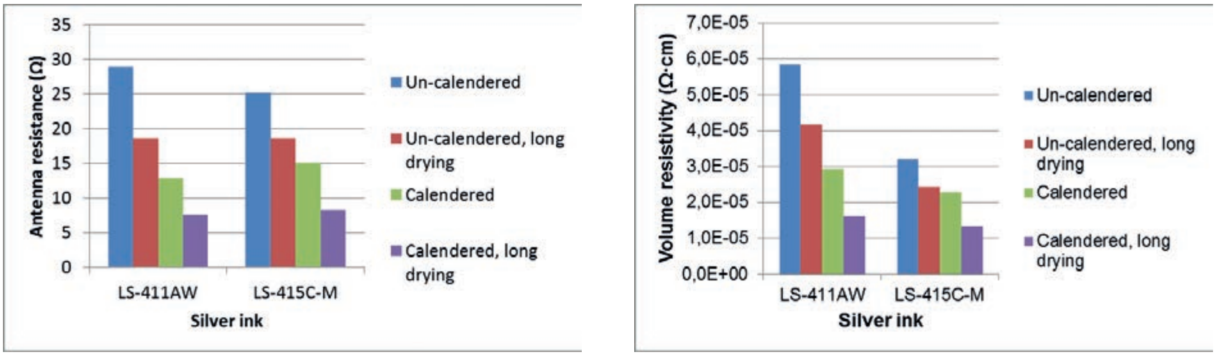


Figure 9: Effect of the calendering and extra oven drying on the LC-circuit resistance (a) and volume resistivity (b) in the case of Asahi LS-411AW and Asahi LS-415C-M silver pastes

The ink layer roughness decreases 72 % during calendering of LS-411AW ink layers. The smoothness of LS-415C-M layers increases 45 %. The smooth metal sleeve surface is copied onto the surface of the printed layer and the ink layer is compressed, thus removing the surface irregularities. The extra oven drying step alone does not affect the layer roughness since only small amount of residual solvents are removed from the ink layer and no mechanical action is caused to the ink layer.

On the other hand, the maximization of the ink layer drying process is highly important in the formation of the layer conductivity, as illustrated in Figure 9. Without calendering, the layer conductivity can be improved 26–36 % by merely drying the printed layers completely. The complete drying of the calendered layer increases the conductance by 40–45 %. In the best case scenario, the optimization of the both calendering and drying parameters can increase the printed layer conductance even by up to 74 %.

R2R calendering can improve the surface properties and conductivity significantly. This typically enhances also the deposition process and surface properties of the subsequently deposited layers as well as the electrical performance of the final devices. Layer smoothness ensures that subsequent layers are easily deposited and they have uniform properties whereas conductivity affects mostly the device performance by enhancing current flow. The properties of the printed layers are typically improved by changing the ink properties and behaviour on the substrate but this often leads to significant changes in the ink spreading, i.e. the detail rendering. Calendering, for its part, can improve surface properties of the printed layer without affecting the ink spreading behaviour. The response of the ink layer to the calendering action depends heavily on the ink layer composition. The ink layer has to contain binders and be compressible to allow proper calendering effects. However, too thin or plain metal layers are not necessarily deformable in the calendering nip. In addition, sintered metal particles might have lost their compressibility. In addition to the calendering process, it is highly important to optimize the drying of the ink layer to maximize its electrical performance.

3.2 Effect of the calendering on the performance of the R2R printed moisture sensor

The printed moisture sensors are sensitive to the changes in the moisture content, as seen in Figure 10 and Figure 11. As the moisture content increases, both the resonance frequency and Q-factor decrease by 7 % and 10 %, respectively. The Q-factor is rather low (4.9–5.6) when the LC-circuit is not calendered, thus making the reading distance small. In this study, the reading distance was 4 cm. Calendering of the LC-circuit increases the Q-factor by 19 % to 6.0–6.5, thus making the moisture sensor performance better. However, at the same time the resonance frequency decreases from 10.24–11.12 MHz to 9.73–10.36 MHz.

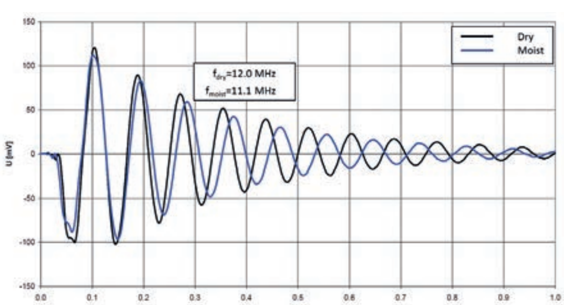
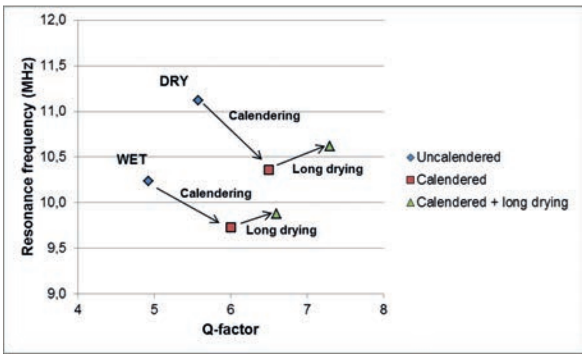


Figure 10: Resonance behaviour of a printed moisture sensor at dry and moist conditions. LS-411AW was the conductor material and CR-18Y2-PI(CK) was the dielectric material.

This might cause problems in the reading process of the sensor since the readers work typically only at a certain frequency. It was found that the resonance frequency can be adjusted by changing the sensor layout without affecting the Q-factor. The complete drying of the printed layers improves also the sensor performance by increasing the Q-factor by 11 % to 6.6–7.3. The resonance frequency increases slightly. LS-415C-M ink gives poorer moisture sensor performance than LS-411AW ink when the LC -circuit layers are calendered. However, when the conductor layers are completely dried the differences between these two inks disappear.

a) b)



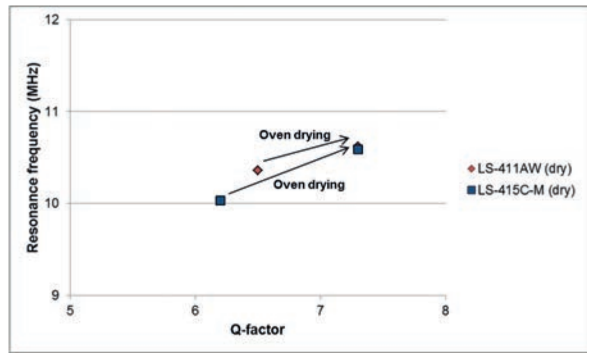


Figure 11: a) Resonance frequencies and Q-factors of the moisture sensors as a function of calendering, long oven drying, and moisture content; under wet environment, the resonance frequencies and Q-factors are lower; b) Effect of the ink type on the Q-factor of the printed moisture sensors; the LC-circuit layer was calendered in R2R process

4. Conclusions

R2R calendering process for rotary screen printed microparticle silver conductor layers was developed and optimized using real R2R pilot printing machines. The calendering improved the layer smoothness and conductivity significantly by compressing the conductor layers. Smooth surface of the calendering sleeve ensured the large smoothening of the printed layer whereas the compression forced metal particles closer to each other by densifying the layer. Low calendering speeds and high calendering temperatures were beneficial for the final properties of the conductor layers. In addition to the calendering, the complete drying of the ink layer maximized the layer conductivity. The calendering was also utilized in the R2R printing of inductively remote readable capacitive moisture sensor and it improved the moisture sensor's performance. The calendering process is very simple and it can be implemented easily to the printing machine construction. It offers an affordable way to improve the conductivity and reduce the layer thickness in the rotary screen printing process of microparticle silver pastes.

Acknowledgements

Authors would like to thank TEKES (the Finnish Funding Agency for Technology and Innovation) and project's industrial partners Polar Electro Oy, Vaisala Oyj, Idesco Oy and Kastelli-Talot Oy for funding and co-operation during the project. In addition, the printing machine operator Mr. Pekka Ontero is gratefully acknowledged.

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JPMTR 055 | 1428
DOI 10.14622/JPMTR-1428
UDC 621.798-035.67+1k-02

Research paper
Received: 2014-07-15
Accepted: 2014-11-24

Study of the effects of the ink layer on selected properties of multilayer packaging films

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Abstract

Application of multilayer films in packaging allows the reduction of the average weight of packaging and a selection of its optimal barrier properties. This kind of material is particularly important for the development of packaging. The aim of this research was to determine the influence of the ink layer thickness on the mechanical properties of interlayer printed laminates. Studies were performed for a double-layer film (poly(ethylene terephthalate)/glue/biaxially oriented polypropylene) prepared by an adhesive method using a two-component, solvent-free adhesive. The bond strength of the laminates and the thickness of each layer were measured. It was found that the thickness of the fixed ink, interlayer printed on the reverse side of the PET film, has a significant influence on the mechanical properties of the laminates. Regardless of the ink film thickness, the values of the bond strengths of the printed laminate are significantly reduced.

Keywords: laminate, double-layer film, interlayer printing, bond strength

1. Introduction

Despite the fact that plastic packaging on a European scale represents only 17 % of the weight of all packages, they are used for more than 50 % of consumer products on the market (PlasticsEurope, 2014). Furthermore, flexible plastic packaging sales grew at an annual rate of 4 % during 1999–2003. In recent years, the fastest growth rates (14 %) were observed on the Eastern European markets. The Russian market has been the fastest growing one, although the USA is the world's largest market. The next largest markets in 2008 were: Japan, UK, Italy and Germany (World Packaging Organisation, 2008). In Europe, packaging applications is the largest application sector for the plastics industry. In 2012, it represented 39.4 % of the total plastics demand (PlasticsEurope, 2013). The most important plastics types are: polyethylene, including low density (PE-LD), linear low density (PE-LLD) and high density (PE-HD), polypropylene (PP) and poly(ethylene terephthalate) (PET).

High efficiency has been achieved in the production of plastic packaging, which allows the reduction of the average weight of packaging. Over the past 10 years this has been reduced by approximately 28 % (PlasticsEurope, 2014). Among other reasons, this was possible through the use of multilayer films, so called laminates.

A proper selection of films for laminate composition allows the achievement of the desired barrier properties and characteristics, such as heat sealability, reduced weight of the packages, etc. On the market, there is no ideal material, but joining the various properties of plastic films (polyethylene, polypropylene, polyesters, polyamides, etc.) or combining them with paper or aluminium film makes it possible to approximate an optimal material, which is a guarantee for a modern packaging with all its required functions.

A literature review leads to the conclusion that research on multilayer film is particularly important for the development of packaging. The number of available publications is still limited and they cover just a part of the subject. Several patents describe novel compositions of multilayer films (Berlin, Bentmar and Flemmer, 2005; Toshiyuki et al., 1996). On a general level, Wagner (2010) describes various problems of multilayer films for use in packaging. Kao-Walter et al. (2004) and Bjerken, Kao-Walter and Stahle (2006) have studied the mechanical properties of a laminate in relation to the kind of materials and the adhesion level. Hare, Moyse and Sue (2012) have published a new methodology for the study of the resistance of laminates to destructive scratching. Taniguchi, Sasaki and Kitamura (2003) have described the possibility of producing multilayer stretch compositions. Quite a large number of publications describe the results of research on the migration of substances from packaging into the packaged food (e.g., Aznar et al., 2011; Ellendt, Gutsche and Steiner, 2003; Lawson, Barkby and Lawson, 1996).

In contrast to studies presented in the literature, the studies presented in this paper concern printing on multilayer films. Multilayer printing has a significant effect on the strength of laminates as well as on its other functional characteristics. This topic is clearly very important due to the fact that more than 90 % of the packages on the market are printed.

2. Methods

The aim of the study was to determine the influence of the ink layer thickness on the mechanical properties of interlayer printed laminates.

Studies were performed for a double layer film prepared by the adhesive method using a two-component, solvent-free adhesive. Liofol 2K (Henkel) polyurethane adhesive was used. Two kinds of films were selected: polyester film (poly(ethylene terephthalate)) and polyolefin (biaxially oriented polypropylene, OPP) (see Table 1). PET/glue/OPP laminates were prepared for the tests in the laboratory.

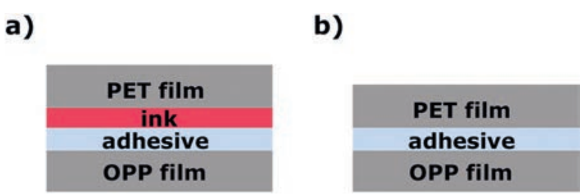

Figure 1: The structure of the laminates used for the tests, a) printed, b) unprinted

The preparation of the laminates included printing on PET film and lamination of the reverse side printed PET film with clear OPP film (Figure 1). Two inks were used for printing: magenta and black (see Table 2). These were special printing inks dedicated to interlayer printing of laminate. Printing was performed using a handheld printer (K Control Coater) with rod applicators. Five rods with different ink transfer to the substrate were used (see Table 3). Then, the printed sheets were laminated with a second film. Constant thickness of the adhesive was achieved by using an appropriately selected rod applicator (number 3).

Five samples of interlayer printed laminates based on each ink colour and with 5 ink film thicknesses were prepared. Multilayer films with the same structure were also produced without printing. The prepared laminates were left until adhesive cross-linking was complete and full bond strength was achieved. After more than 14 days, their mechanical properties were tested and a microscopic analysis was performed.

The bond strength between two films was analyzed using a Zwick tensile tester FB010TN.D30 BT1. Samples for the delaminating process were prepared according to standard (International Organization for Standardization, 1995). Strips of 15 mm width were cut. Their edges were smooth and without damage. As the first step, the laminate strips were partially pre-delaminated. For this purpose, they were dipped into Chesoll for 15 minutes. Then they were mounted in the tester and subjected to the tear and peel test. The tester settings were as follows: the initial distance between the holding jaws – 50 mm, test distance – 100 mm, test speed – 100 mm/min.

At the end, the structure of the prepared laminates was examined using an Olympus optical microscope.

Table 1: Characteristics of the films

	Film	
	OPP	**PET**
Film name	BIFOL BG	BOPET CA
Producer	Flexpol	Flexpol
Thickness [μm]	20	12
Orienting type	biaxial	biaxial
Surface activation	yes	yes
Roll width [mm]	560	560
Density [g/cm^3]	0.9	1.4
Grammage [g/m^2]	18.2	16.8
Haze [%]	2	4
Gloss 45°	90	–

Table 2: Characteristics of the inks

Ink	Ink name	Type	Producer	Light fastness
Black	Process Magenta Raster	F-62GSR35206-0301	Michael Huber	6
Magenta	Process Black Raster	F-69GSR66006-0301	Michael Huber	6

Table 3: Characteristics of the rods

Rod number	Wound type	Wire diameter [mm]	Wet film deposit [µm]
1	close	0.05	4
2	close	0.08	6
3	close	–	10
4	close	0.15	12
5	close	0.31	24

3. Results

In this work the influence of interlayer printing with different kinds of ink on mechanical properties of the laminates were studied. The results of the delaminating tests for unprinted multilayer films are shown in Figure 2.

An analysis of microscopic images made it possible to measure the thicknesses of the individual layers of the composition of the film: the films, the fixed adhesive and the ink layers. This knowledge may help to better understand the impact of the thickness of the ink layer. A sample photo of the structure of the interlayer printed laminates is presented in Figure 3.

The results represent the bond strength of 5 samples. All tested strips came apart almost immediately after the beginning of the tear and peel test (see c) in Figure 4). Although the test distance was set up at 100 mm, the samples were fractured after just a few mm of the tear and peel process (see Figure 5). This observation indicates the high strength of the laminates and their good quality.

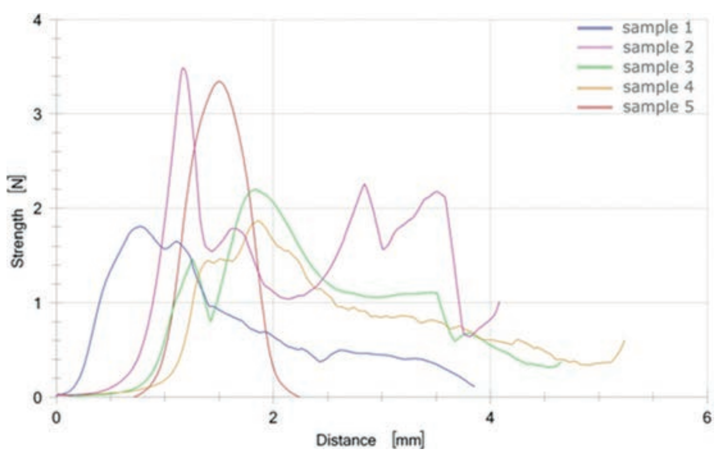

Figure 2: Bond strength of unprinted laminates

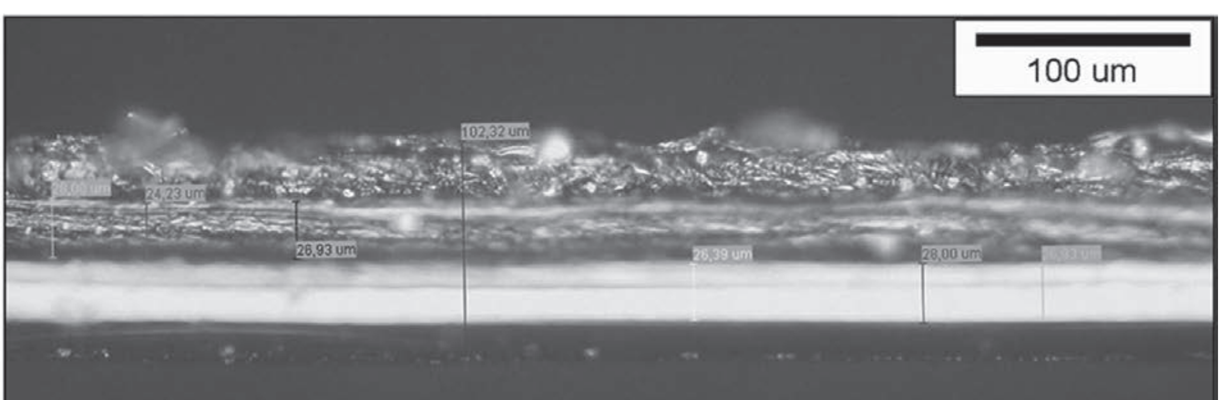

Figure 3: Sample photo of the structure of interlayer printed laminates

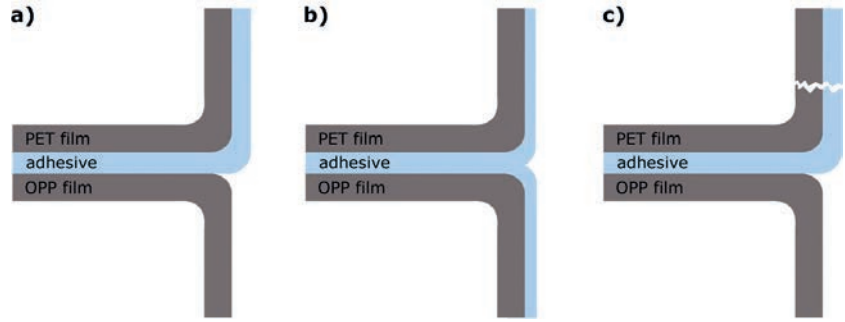

Figure 4: Types of bond failure during the tear and peel test a) adhesive bond failure, b) cohesive bond failure, c) film breakage

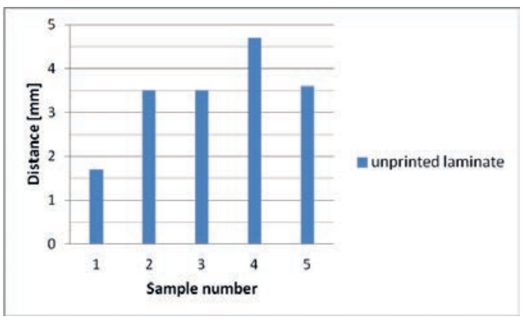

Figure 5: The distance between the tensile testing machine jaws after which the samples of unprinted laminates were broken

The bond strength of the interlayer laminates was determined. The results received for multilayer films printed with both kinds of ink and different ink thicknesses are presented in Figure 6.

The ink layer has a negative impact on the bond strength of the laminates. The ratio (P) of the maximum bond strength of interlayer printed laminates to the maximum bond strength values obtained for unprinted laminates is shown in Figure 7.

$$P = \frac{\max \mathit{Bond\ Strength\ of\ interlayer\ printed\ laminates}}{\max \mathit{Bond\ Strength\ of\ unprinted\ laminates}} \cdot 100\%$$

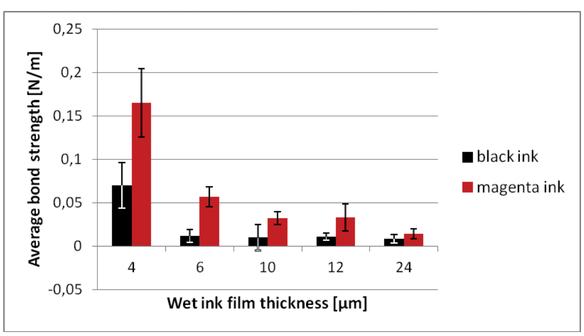

Figure 6: Influence of the ink film thickness on the average bond strength of interlayer printed laminates

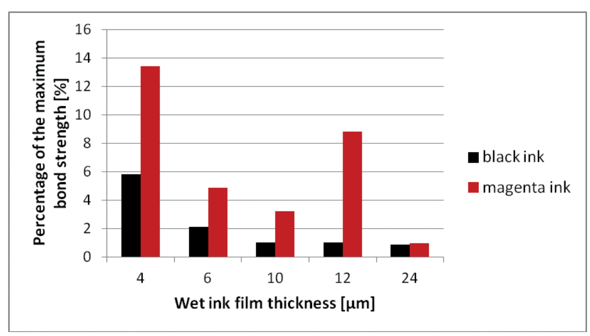

Figure 7: Changes in the maximum strength of interlayer printed laminates in comparison to unprinted ones

4. Discussion

The bond strength of laminates with and without interlayer printing was analyzed. In the case of laminates without interlayer printing, all tested samples came apart, and the value of the maximum bond strength was more than 3 N/m for 2 stripes and approximately 2 N/m for the rest of samples (see Figure 2). The value of the average bond strength was consistent with data suggested in the literature. For all laminates, the PET film was broken during the tear and peel test. In addition, the distance between the tensile testing machine jaws after which the samples of unprinted laminates were broken (Figure 5) was lower than 5 mm, when the maximum distance of the test was 100 mm. This indicates that the quality of the laboratory prepared laminates was very high and that the adhesion of the adhesive to both films was good, as well as that the polyurethane adhesive was properly chosen. Furthermore, the substrate strength was lower than both the adhesive and the cohesive bond strengths.

For both kinds of printed laminates, the bond strength was significantly lower than for the unprinted composition, regardless of the choice of magenta or black flexographic ink or the thickness of the applied layer. All samples were delaminated and two kinds of failure were found. Adhesive bond failure was observed in most cases. Cohesive bond failure occurred usually together with the adhesive one, appearing separately only in very small number of cases (Figure 4). During the delamination process, the fixed ink layer was transferred from the PET film to the OPP film for almost all samples. This means that the adhesion of the ink film to the printed substrate (PET film) was lower than adhesion forces between ink film and adhesive. This also indicates high cohesive forces within the fixed ink layer.

The thickness of the printed ink layer has a significant effect on the bond strength of laminates. With an increase in the thickness of the ink layer, the bond strength decreases rapidly. The highest values of average bond strength for the interlayer printed multilayer film were obtained with a rod applicator that allows for the wet ink layer a theoretical thickness of 4 μm (see Figure 6). However, even in this case the bond strength values were much smaller than for unprinted laminates. The values of the maximum bond strength obtained for interlayer printed laminates were 6 and 14 % of the values determined for unprinted multilayer films, for black and magenta ink, respectively (see Figure 7).

The type of ink used determines the mechanical properties of the laminates. The values of the average bond strength for the laminates printed with magenta ink were higher than for those printed with black ink. The magenta ink film thickness had a significant impact on the bonding strength of the laminates. The ink film thickness is not as important in the case of black ink, but the influence can also be observed (Figures 6 and 7).

The microscopic analysis shows that the settled layers of ink and adhesive were of fairly uniform thickness for all the laminates (see Figure 3). This confirms the good quality of the laboratory preparations and shows that no uneven layers were produced in the lamination process. Furthermore, the study found that the fixed layers of ink and adhesive were of much larger thickness than expected. This result suggests that the wet layers produced by the rods were several tens of percent thicker than what the rod designation specified. This did not have an important influence on the results, because the order of ink layer thickness was maintained and the experiments covered a wide range of ink thickness values.

5. Conclusions

The research found that the thickness of both the adhesive and the fixed ink layer has a significant influence on the properties of the packaging material. This impact is not limited only to the possible migration of compounds hazardous to health and flavour into the product, but has a negative influence on the aesthetics of the package, defined as the quality of the print and the quality and durability of the lamination. The thickness of the ink layer in interlayer printed double-layer films determines their bond strength in the delaminating tests. Regardless of the thickness of the ink layer, the values of the bond strength of printed laminates are significantly reduced.

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JPMTR 056 | 1420
DOI 10.14622/JPMTR-1420
UDC 159.937 (084) 621.798

Research paper
Received: 2014-07-15
Accepted: 2015-02-13

Visual perception and recollection of pictures in packaging design

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Abstract

Continuing an ongoing study to analyze consumer reactions to packaging design, eye tracking test results that explore the visual perception and recollection of pictures in packaging design are presented. Particularly, the extent and reliability of human recollection of pictorial elements on packages that were seen only for a short period of time is discussed in detail. These results help to better understand the visual impact which pictures in packaging design have on consumers. The results suggest that consumers discern a great deal of graphical detail in pictures within a very short period of time, but that this recollection varies among users and is sometimes inaccurate. Furthermore, it could be shown that viewers in general describe coherent (albeit sometimes inaccurate) interpretations of visual stimuli instead of isolated details of visual design.

Keywords: packaging design, eye tracking, qualitative content analysis, visual perception, picture

1. Introduction

The design of packages in which products are presented to consumers at the point of purchase has long been understood to influence the attention, evaluation, and ultimately purchase decision of consumers (cf. Piqueras-Fiszman et al., 2013, p. 328). At a time when products have to compete with hundreds of others in the shelves (Munzinger and Musiol, 2009, p. 235), whose properties are becoming increasingly similar (cf. Hinz and Weller, 2011, p. 234), it becomes more and more important for packaging designers to understand those factors that influence the consumer's behavior, motivation and (buying) decisions (cf. Bittner and Schwarz, 2010, p. 18).

It is generally assumed that packaging design indeed does stimulate emotions, and that the emotional impact packaging design has on consumers is influenced by such factors as the size or shape of the packaging, graphic and surface design, color or typography (cf. Hinz and Weller, 2011, p. 236; Duchowski, 2007, p. 263). In particular, pictures are traditionally believed to have a high emotional impact on consumers (Munzinger and Musiol, 2009, p. 67), to add an emotional appeal to a product (Busch, 2007, p. 5) or to be better suited to catch the viewer's attention than text elements (Busch, 2007, p. 40). Designers trying to use pictorials in a purposeful and appropriate way need to understand how images are perceived and especially which of their visual components stay in mind and make an illustration the most efficacious.

In order to better understand the visual impact packaging design has on consumers, several of them have been analyzed in a series of eye tracking studies (Nikolaus and Lipfert, 2012; Nikolaus and Geissler, 2013). Among other interesting results clarifying the emotional impact of packaging designs or the importance of color, these previous studies also led to some astonishing results as to the relationship of text and images, respectively. In both studies, pictorial stimuli (such as product shots or a background image) consistently had a lower attentional impact and were also looked upon later than textual stimuli (particularly the product or brand name). This was unexpected, as chocolate boxes with richly illustrated, colorful designs were analyzed, that were supposed to have a higher tendency to attract attention (Wedel and Pieters, 2008, p. 50) than a text would have in the same place, which should have led to an increase in the average fixation duration (Piqueras-Fiszman et al., 2013, p. 331).

However, in post-test surveys, the test viewers nonetheless attributed a high emotional importance to the pictures on the packaging. This is an astonishing result, as it seems improbable that a visual element that is hardly looked at has a high impact on viewers. Familiarity aspects (the notion that pictures are largely ignored because the package was well-known to the viewer and therefore needs only a short gaze for recollection) could be ruled out (Nikolaus and Geissler, 2013).

One possible explanation, however, might be that processing or recollection of texts is significantly harder than that of images (an assumption also expressed by Busch, 2007, p. 39), and that therefore, the amount of attention paid to pictorials is often lower than the amount paid to text (cf. Duchowski, 2007, pp. 263–265).

Hence, the aim of this study was to better understand the perceptional impact pictorials have in packaging design and, more precisely, what and how much information test viewers can extract from a picture while looking at a package with only a cursory glance (as it is usually done at the point of purchase). If pictorials (both product shots and background images) are only fixated for a comparative short period of time, they may well be noticed – but can their meaning be extracted accurately, completely and reproducibly?

In order to answer this question, test participants were asked to look at several unfamiliar packaging designs for only a short period of time. Immediately afterwards, they were asked to describe the images included therein as precisely as possible. Thus, it was to be determined what aspects of the images were remembered best, and if there were any differences in the statements that could be attributed to differences in the packaging design. Furthermore, these results were combined with eye tracking data in order to find out which correlations between the distribution of visual attention and the reliability or elaborateness of the statements could be identified.

2. Research methods

The study described in this paper consisted of two parts. In the first part, the viewer's reaction to various packaging designs was analyzed using eye tracking technology. In the second part of the test, the visual perception and recollection of the pictorial elements of the packaging design was tested by conducting structured interviews for each of the test participants. The research design was as follows:

Subjects: Twenty-two second and fourth-year students (15 males, 7 females) were recruited for the experiments. They had normal or corrected vision, and their age was 19 to 30 years, with 25 years on the average. Although all attended basic lectures on visual media design in their first year, none of them had special knowledge in packaging design. As the eye tracking part of the test was identical to the one already described by Nikolaus and Geissler (2013), in total, forty test participants (25 males, 15 females; aged between 19 and 37 years with 26 years on the average) performed the first part of this test.

Stimuli: As the eye tracking system used for this test was computer-based, two-dimensional reproductions of the packages were shown to the test participants on a 17" LC display in random order. To use the screen resolution to its full capacity, all samples were in landscape format. All packages were reproduced photographically and then retouched using an image processing program to obtain a realistic recreation. All designs were then shown to the subjects on a dark background; one sample at a time, each display lasting five seconds. Using eye tracking technology, the overall distribution of attention was recorded for each participant and sample.

Figure 1: Overview of test samples used in the both parts of the test. In the eye tracking part, full reproductions of all chocolate boxes were used, whereas in the interview part, product shots and background images were covered by a monochromatic mask that had more or less the same color as the background, only a little lighter or darker. For the sake of clarity, in this figure outline renderings of the hidden images are added to give readers an impression of the images behind the masks.

All samples had previously been used for another eye tracking test (Nikolaus and Geissler, 2013) so that results could be compared directly. Again, seven chocolate box designs in landscape format were used that contained neither obtrusive discount markers nor transparencies, holograms, embossments or other effects (cf. Figure 1). These samples had been the seven most unknown designs out of a set of originally 24 designs in the previous test, and they were comparably unfamiliar to the participants of the actual test (which was tested in a post-test survey). The seven unknown samples were once again supplemented by two rather well-known designs. Only the unknown designs, however, were used for the interviews in the second part of the test.

Apparatus and procedure: The stimuli were presented on a monocular, desktop based NYAN 2 XT/EDGE eye tracking system produced by Interactive Minds, Dresden (Interactive Minds, 2013). A Samsung SyncMaster 17" TFT display with 1280 × 1024 pixel resolution was used at a sampling rate of 60 Hz rate and 0.45° accuracy. The samples were slightly enlarged in order to compensate for the lower resolution of computer screens.

User reactions were recorded and their visual scan paths analyzed. In order to assess the relative importance of the main visual components on the sample packages (brand name, logo, product name, product shot, etc.), Areas of Interest (AOI) were defined beforehand in order to compare fixation counts, the time to first fixation, gaze durations, etc.

Interviews: Immediately subsequent to the first part of the test, the packaging designs were shown to the test participants once again. This time, however, all pictorial elements were covered (cf. Figure 1). The test participants were now asked for each of the seven unknown designs (one at a time) to describe the masked images (both product shots and background images) as accurately as possible. In order to help them to give a comparatively thorough picture, the keywords alignment, color, contrast, shape, size and texture were mentioned to them if they had not referred to them on their own. These keywords were chosen from a list of design elements compiled by Watson (Watson, 2003) from several art and design textbooks attempting to harmonize design terminology. From the seventeen components of design identified by Watson, some (like motion, sound, taste & smell or space (three-dimensionality)) were obviously not applicable here, whereas others (like balance, clarity, focus or unity) described design principles or design laws that are beneficial in the design process but less suited for image description. Thus the original list of seventeen components was narrowed down to the six visual features mentioned above. An audio recording was done for each interview.

For the analysis of the audio data, a structured content analysis (a variant of the qualitative content analysis method developed by Mayring (2000)), has been used. In compliance with this method, for each of the six visual components under analysis (alignment, color, contrast, shape, size and texture, respectively), a structured and comprehensive system of evaluation categories was inductively developed on the basis of the interview data. For each of the categories, characteristic criteria were defined and exemplary answers defined. This was done to both avoid assumed meanings in the data transcription and the following evaluation process and to allow for a numerical comparison of the recorded answers in order to obtain generalized conclusions.

Table 1: Extract of the coding agenda for the property "base color". The example refers to a dark blue background image.

Property "Base Color"	Definition	Example	Coding Rule
C1: Correct base color description given	Unambiguous specification of base color	"The main color was blue"	Base color must explicitly be named
C2: Partially correct color description given	Correct naming of base color, but incorrect or erroneous naming of shade or contrast	"Blue with shades of yellow" or "Blue, rather a medium blue"	Base color must be named correctly, additional statements may be incorrect or contradictory
C3: Incorrect color description given	Incorrect specification of base color	"Yellow with white highlights"	Description of base color is completely wrong
C4: Appropriate color reference used	Correct usage of a reference to describe the base color	"Midnight blue" or "Cornflower blue"	Reference must be unambiguous and verifiably associated to the base color
C5: Inappropriate color reference used	Incorrect usage of a reference to describe the base color	"Red like tulips"	Reference obviously refers to a different base color
C6: No base color statement given	No base color could be described	No statement	No statements concerning this property are made

Next, the answers of the interviewees were assigned to these categories and the definitions and examples were adjusted and refined, where necessary. In this refinement phase, the categories "shape" and "size" were merged, because statements as to the size were mostly done in combination with the shape (if there were any at all, because information about the size of objects could in general be derived from the size of the masking area visible on the test samples). Differences in contrast, on the other hand, were hardly ever described alone, but rather as different shades of a base color. Therefore, the respective categories were renamed to "base color" and "color shade". A new category "color references" was created, because it became apparent that many interviewees used references to previous viewing experience in order to describe a certain shade of color. All category definitions, definition examples and coding rules were then distilled down to a so-called coding agenda which provided the basis for a comprehensive, objective and impartial classification of the interview material (an extract of the coding agenda is shown in Table 1).

3. Results

3.1 *Basic color, color shade and color reference*

The test viewers were quite successful in remembering the main color for most of the designs. To memorize a particular shade, however, seems to be more difficult, as the number of participants that could remember no color shade for a certain pictorial was in general higher than the amount of test subjects that were able to describe it correctly (cf. Figure 2). Exceptionally good was the shade description of sample no. 1, where 15 out of 22 stated that the background image is of the same color as the plain blue background, only a little lighter. Unusually high (10 out of 22 participants) was the amount of incorrect statements as to the color shade for sample no. 4, where statements like "dark" (4 out of 22) or "dark brown" (6 out of 22), "red brown" (2 out of 22) or "coffee-colored" (1 out of 22) were used. This, however, rather describes the shade of the background or the color mask, respectively, whereas both the background and the product shot are lighter and less red.

The two designs where the main color was most difficult to remember were samples no. 5 and no. 7 in Figure 1 (10 out of 22 participants had no color recollection for the first one; 5 out of 22 had a wrong and 4 out of 22 no recollection for the second one, respectively). Sample no. 5 is multi-colored, using white and two different shades of brown. These two colors, however, were only remembered by 9 and 12 out of 22 test participants; others only mentioned "several" colors (8 out of 22). 7 out of 22 thought that the products shots have the "same color as the background" – although this is only true for one of the four corners where the images are placed; whereas in the other three, contrasting colors are used. Only one test viewer was able to describe this correctly.

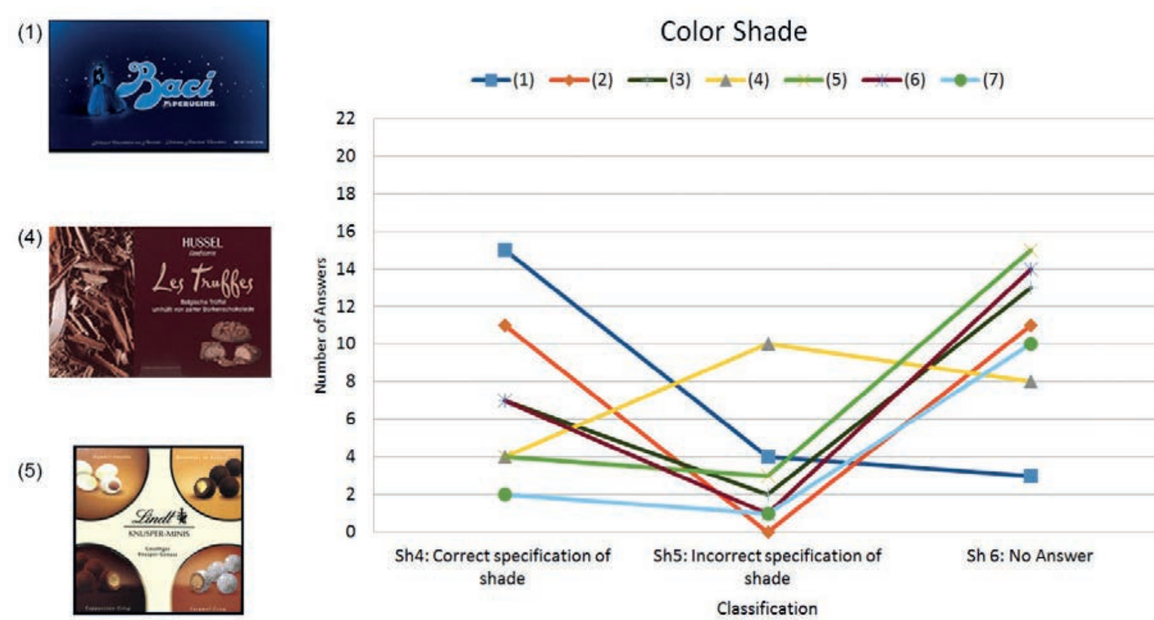

Figure 2: Sample results of the structured content analysis, visualizing the recollection of color shades. The recollection is best for sample no. 1, where the shade of the image is similar to the one of the background. Answers are often incorrect for sample no. 4, where the shade is substantially lighter than the background. The number of missing answers is highest for sample no. 5, which uses many different shades of white, yellow and brown.

Sample no. 7, on the other hand, uses colors that are quite unusual for chocolate boxes (yellow and purple, respectively), and is designed in an unusual comic style. Here, some test subjects mistakenly believed to see "red lips", "bright, neon colors" or "high-contrast, gaudy colors" that are "flashing" (one statement each). The purple color was remembered by 12 and the yellow by 8 out of 22 test subjects; others thought they had seen the colors "red" (5), "blue" (4) and "green" (2), although the only additional color values used are black (remembered by 2) and white (by 1).

A sample with an unusually high number of mistakes whilst describing the base color (6 out of 22) was sample no. 2. This box of mint chocolates shows several dark brown, round pieces; some of them in golden or light green wrappings. However, only 4 of the test subjects were able to name three different colors at all – and in each case, one of them was wrong (black/brown/white was mentioned twice; black/gold/green and brown/green/"light-colored" once each). Ten other participants at least mentioned two colors, 8 of them correct ones. Among the colors mentioned most often were "brown" (16) and "green" (11). "Gold" was mentioned 4 times, "something light" twice and "yellow" once. Again, some colors that were *not* used in the pictorials were named repeatedly, particularly "dark green" (4; this is the background color), black (4) and white (3). For design no. 2, many color references were used by the interviewees. Such references were also used elsewhere; mostly to describe color shades ("cappuccino-", "coffee-", "salmon-colored" and so on). Sample no. 2, however, was once described as resembling "Beck's crown caps" (Beck's is a German brewery that uses a tall ship with light green sails in its commercials and sells its products in light green beer bottles – although both labels and crown caps are silver) and repeatedly as being "similar to After Eight" (5 out of 22). Although package no. 2 does indeed contain mint chocolates, the analogy in design is de facto lower than assumed by the interviewees: the background of sample (2) is mostly black rather than green, the chocolate pieces are round instead of rectangular, the wrappings are gold and light green and not black with a golden clock, and on some "After Eight" packages, a white mint filling is visible that is absent from the design in the test (although 3 out of 22 test viewers thought they had seen something white here).

3.2 *Shape and size*

Apart from color recollection, form recollection was tested as well. In general, it can be stated that the form of products was remembered more reliably than that of background images (although almost all products were either round or oval, which made guessing considerably easier). The highest number of erroneous statements (5 and 4 out of 22) and missing statements alike (13 and 8 out of 22) could be found for samples no. 4 and no. 6, respectively. The most common mistakes for sample no. 4, which features flat oval truffles covered with milk chocolate shavings that give them a somewhat irregular appearance, was that the pieces were simply described as "round" (4) or "rectangular" (1).

A very detailed background image is visible on sample no. 3, which shows a row of paper flowers with two leaves on each side and truffles instead of blossoms. These paper flowers are standing on a geometric pattern consisting of semicircles with a little hole in the middle, faintly resembling ribbon embroidery. Although many test viewers were able to describe one aspect or another, no one remembered both: 10 out of 22 interviewees described the flowers and three the embroidery; two thought they had seen a picket fence, and one each an alley of trees, musical notes or truffles on a stick.

Some product shot/background interdependencies could be identified for sample no. 6, which features a detailed background image showing a line drawing of a historic square. This picture was described by some interviewees as "agitated", "cluttered" (2), "detailed", "difficult to interpret", "distracting" or "interesting" (one each unless otherwise specified). Here, 12 out of 22 test viewers were unable to describe the product form correctly (4) or to remember anything about the product shot at all (8) – whereas 20 participants made descriptions of the background image (14 of them without fault).

A lot of confusion was also caused by the unusual, comic-style background in sample no. 7, which was described by the viewers as "abstract", "arty", "candy-like", "chaotic", "crowded", "distorted", "overburdening" or "a little weird" (one each). Here, a young woman with gloves amidst purplish bubbles in various sizes is shown – but this drawing was, amongst others, interpreted as "a clown", "a cat", "a figure with a purple hat", "mice", "something like Pluto or Mickey Mouse", or "a boy wearing a base cap" (one each). Much higher, in contrast, was the degree of consensus for a small fair-trade logo in the upper right corner of the design: it was described by 10 of the 22 viewers.

Each and every test participant (22 out of 22) was able to describe the form of the background image of sample no. 1 – showing a young man and a woman standing close together; the only instance of a depiction of human forms apart from the comic character on sample no. 7. The wide skirt of the woman was remembered by 9 out of 22, as was the relative position of the couple (by 16 out of 22) – although several (18) stated that the couple was "dancing" instead of "kissing" (the real meaning can be derived from the brand name "baci", which means "kisses" in Italian). Some even used explicit references (e.g. "looks like Beauty and the Beast"; 4 out of 22).

Another interesting result is that the coat of arms that is visible above the brand name on sample no. 2, albeit no image in the narrower sense, was not mentioned by anyone of the test viewers – neither the form, meaning, color nor position.

3.3 *Texture*

The texture of products was hardly ever remembered. Only for the samples no. 2, no. 3, no. 4 and no. 5 a mentionable number of texture references (i.e. more than one or two) was made. The highest number of erroneous statements could be found for sample no. 2, where only one correct (albeit very short) answer but five faulty answers were made. The latter correctly described that the pieces in this box are not smooth, but assumed that the chocolates are covered with "chopped" or "slivered" nuts, with "coconut flakes" or "chocolate sprinkles" (in reality, however, the pieces either have a ribbed texture or an engraving of the brand name on top). Other references (6 and 8 out of 22, respectively) as to the texture were found for samples no. 3 and no. 5 that both contain an assortment of truffles with varying appearance. Although the number of faults was considerably lower here, it is worth mentioning that none of the test viewers making statements about the texture described more than two different ones, although the pieces in sample no. 3, for instance, have five different forms of decoration.

Same associations (6 out of 22) as to the texture were also made for sample no. 4, were the chocolate flakes texture was mistaken for chopped nuts in two cases (another participant used a reference to Ferrero Rocher, which has an irregular surface as well, but is also covered with nuts).

3.4 *Alignment and position*

Another interesting result for the sample no. 4 was that several participants confused the position of the background image showing chocolate flakes (left-hand side) with that of the product shot (right-hand side). Of the 16 test viewers that described alignment and number for this sample at all, 15 described these properties for the truffles, but only 7 for the chocolate shavings. Six of them thought they had seen truffles on both sides of the design, and three mixed up the position of the flakes and the products. Detailed descriptions of the products were given by 8 interviewees, the form of the background image, however, was only mentioned by 4 – and there was only 1 participant that gave a detailed description for both pictorials.

In general, statements as to the alignment and the position of the products were highly inaccurate and had a great variety. Sample no. 5, for instance, featured three entire and one sliced chocolate pieces in each of the four corners, hence 16 in sum. Six of the test subjects, however, thought that they saw 1 piece in each corner, one 1–2, four 2–3, one 2–4, two 3, two 3–4, one 3–5, one 4–5 in each corner, whereas one thought he saw 2–3 and one 3 pieces on the whole. Similar results could be found for sample no. 3, featuring three paper flowers and seven flowers with truffles instead of blossoms. Again, the answers of the test participants varied considerably: some thought that they had seen 5 flowers (three viewers), two thought they had seen 5–6, two 6–7, two 7, four 8 and two 8–9, whereas others gave the numbers 4–5, more than 5, 5–8, 6 or 6–8 (one mention each for the latter).

Some interviews even contained obvious contradictions that were not even noticed by the participants: One interviewee, for instance, stated that both the man and the woman in the background image in sample no. 1 were standing in front of each other; another thought that the total number of chocolate pieces visible in sample no. 5 was four, and that in each corner of the package, one whole and one sliced piece of chocolate was to be seen (in reality, the number of visible pieces was sixteen).

4. Discussion

The results show that viewers do indeed remember a lot of details of the covered pictorial elements, even if these stimuli are only looked at for a short period of time. However, their recollection is often diffuse and, in some cases, inaccurate. The level of detail and the specifics remembered differed widely amongst test participants, possibly dependent of the viewers' level of interest or their likes and dislikes in the context of certain chocolate flavors. In two cases, at least, interviewees had an extraordinary detailed recollection of a design that they referred to as "spirited" or "the most beautiful of all", whereas two other viewers had almost no recollection of a design that they considered to be "failed" or of a product they thought to be "unaffordable". This influence of emotional affordance on image understanding has also been mentioned in (Busch, 2007, p. 29) or (Wedel and Pieters, 2008, p. 38).

In general, it was quite difficult for the interviewees to remember discrete categories like size, the number of elements, color and so on. The wording of most statements suggests that, instead of discrete design elements, they rather remembered more complex, interlinked interpretations of what they had seen. These interpretations may in some cases even contain obvious contradictions (two persons both standing in front, one whole and one sliced piece of chocolate in each of the four corners add up to four chocolate pieces in sum) that were not remarked by participants. This is in accordance with results stating that people's visual scan of an image is often not exhaustive (Duchowski, 2007, p. 263), that their information extraction is very selective (Hayhoe and Ballard, 2011, p. 610) and that objects are often only partially recognized (Findlay and Gilchrist, 2009, p. 136). van der Lans, Pieters and Wedel (2008, p. 929) state that consumers use only one or two basic features of an image at the same time when trying to find a brand rapidly and accurately.

The notion that perceived graphic entities are bound together to form a coherent representation in the viewer's mind can also be found in several studies (e.g. Treisman and Gelade, 1980, p. 97; Hayhoe and Ballard, 2011, p. 610, or Hochpöchler et al., 2013, p. 1108). This internal model might also play an important role in image recollection (see below). This combination of only a limited number of perceptually outstanding visual features into a coherent visual representation allows for an efficient information processing and a quick recognition and comprehension of the basic meaning of an image, but is less suited for a complete and reliable identification of visual details (cf. Stiller, 2000, pp. 65–68).

A comparison of the respective visual components showed that the recollection of the *base color* of a design was more reliable for monochromatic designs than for polychromatic ones, where it was even difficult for some test subjects to name any color at all. The recollection of main colors was in general better than the recollection of shades. Similarly, statements describing the basic *form* of a depiction were often more accurate than those concerning minor details or the texture of the respective objects. Generally speaking, the recollection of color and shape was more reliable than that of other visual components – which matches results from van der Lans, Pieters and Wedel (2008, p. 54) stating that colors and edges have strong effects on both localization and identification of brands on shelves.

One of the more difficult tasks for the test participants obviously was the recollection of the *alignment*, the *position* or the precise *number* of chocolate pieces shown on the more complex designs. The higher the level of detail of a given pictorial, the higher was the number of erroneous statements. In the majority of cases, the recollection of the test participants tended to be less complex than the original: instead of three different colors in sample no. 2 or five different textures in sample no. 3, most viewers described not more than two, respectively; instead of sixteen chocolate pieces in sample no. 5, they believed to see 8 to 9 on average. Similar objects tended to be interpreted as a group, and properties tended to be generalized. For instance, all chocolate pieces of sample no. 2 or no. 3 were said to be round (although some of them were rectangular); in sample no. 4 and no. 5, several viewers thought they had seen only *one* truffle in the product shot areas, although there were two and four, respectively. Apparently, participants prefer to focus on only a small number of objects. If there are, for instance, two pictures on a package (cf. sample no. 4 or no. 6), test viewers tended to remember only one of them, but seldom both.

Thus, the amount of visual complexity of the stimuli seems to play a crucial role in image understanding. Although it has already been stated (e.g. in Geisler and Cormack, 2011, pp. 440–441), that the complexity of selected stimuli may exceed the capacity of selected neural processing and can make a perfect performance impossible, it is nonetheless remarkable how low this threshold really is.

Apparently, product shots generally get more attention than background images – but detailed images got more attention than simple ones, and might even withdraw attention from other design elements. Only very few participants, for instance, were able to correctly recollect the color, form and number of chocolates pieces visible on sample no. 6 with its very fine-grained background image. Likewise, there were several mix-ups between product shot and background image properties while describing the sample no. 4. This is consistent with recommendations from Duchowski (2007, p. 274) and Wedel and Pieters (2008, p. 28), advocating a clearer or less heterogeneous background in the context of print advertising.

Furthermore, the viewer's recollection seems to be influenced by the environment in which the pictorial elements were placed – an assumption that can also be found in (Treisman and Gelade, 1980, p. 98). Many viewers, for instance, thought that the product shots on sample no. 4 showed dark brown pieces made of bittersweet chocolate. In reality, however, the chocolate pieces were light brown and made of milk chocolate (the background, however, had the dark brown color that the viewers described). In another case (sample no. 5), chocolate pieces were also said to be "of the same color as the background" – although this was only true for one of the four corners were the images were placed, whereas in the other three, contrasting colors had been used. Likewise, textual product descriptions on the package seemed to influence the statements, as well as the brand name: the term "symphony" on sample no. 3, for instance, led one interviewee to believe that he had seen musical notes. Another one believed that sample no. 7 showed a cat after he read the label "Mitzi blue" (possibly because of the similarity to "Mieze", which means "kitty" in German).

Unusual designs that were rather atypical for chocolate boxes seemed to be comparatively more difficult to remember than middle-of-the-road ones. Stylized paper flowers on sample no. 3 were mistaken for alleys or picket fences, the comic drawing on sample no. 7 for a clown, mice, or a boy wearing a base cap. On the other hand, well-known graphical symbols like logos or ecological seals were frequently remembered.

Equally interesting is the fact that participants used a lot of references to previous viewing experiences. For instance, a kissing couple was said to look like a scene from the animated film "The Beauty and the Beast", or a box of mint chocolates was often described as being similar to the product "After Eight". In the latter case, properties of the referred package were even erroneously transferred to the test sample. This connection between brand differentiation and familiarity was discussed in detail by van der Lans, Pieters and Wedel (2008, pp. 929–930). In order to increase brand differentiation, a packaging design has to be designed differently from its competitors. If, however, a brand is overdifferentiated, this might lead to brand confusion, so that the corresponding product might not be recognized as belonging to the respective product category and may not be found easily on the shelves.

5. Conclusions

The image recollection of the test participants is varying, but in sum rather detailed, albeit often inaccurate. The properties of these images are, in general, only remembered fragmentary. The higher the "visual clutter" (i.e. the number of visual elements that compete for the attention of the test viewers), the higher becomes the danger that elements are remembered incorrectly or that details are completely forgotten. Therefore, the number of graphical elements on a package should not be too high, because viewers can only focus their attention on a rather small set of visual elements. Visual elements that are supposed to be background elements should not be too big, too colorful or too detailed so as not to withdraw attention from more important elements such as, for instance, product shots. Here, it seems to be important to carefully choose the right level of detail, a sensible, limited number of visual elements and to find a well-balanced equilibrium so that no visual element may capture the viewer's attention at the expense of others.

As for the packaging designs, too unorthodox designs tend to irritate the viewers and lead to a poor recollection or even to a mix-up of product categories (candy instead of truffles). It seems that a certain similarity to competing products is preferable, because this eases recollection. Too much similarity, on the other hand, is prone to threaten product differentiation, thus making a product indistinguishable from its competitors (for a more detailed discussion of this aspect, see van der Lans, Pieters and Wedel (2008)). The challenge seems to be to create a design that is in line with the expectations of customers without losing its individuality.

As for the obvious differences in text and image processing that have already been discussed in Nikolaus and Lipfert (2012) and Nikolaus and Geissler (2013), it can now be stated that text and graphics play fundamentally different roles in visual perception and recollection – a statement also to be found in Hochpöchler et al. (2013, p. 1120). This is consistent with results from Piqueras-Fiszman et al. (2013, p. 332), stating that the substitution of a text with a photo on a jam jar design had highly significant effects on the attention paid to the respective elements. In the context of print advertising, Duchowsky (2007, pp. 265–267) also found that viewers spent much more time viewing text than viewing pictures in these ads, deducing that consumers may be paying much more attention to text than previously thought.

Further research could investigate this text-image relationship in the context of packaging design in greater detail, especially with regard to the interplay of text and graphics in getting the viewer's attention, improving the product differentiation and influencing buying decisions. Apart from a mere examination of packaging design stimuli and their corresponding visual components, the influence of emotional responses and their impact on the perception and recollection of packaging designs might be analyzed as well.

Acknowledgements

The authors would like to thank both André Göhlich and Nadia Nikolaus for their invaluable help in preparing and performing the test as well as in editing the test results. Klaus Stiller is warmly thanked for fruitful discussions and his helpful suggestions.

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Professional communications

JPMTR 1411
DOI 10.14622/JPMTR-1411
UDC 655.1 : 762-035.67 | 66-97

Professional communication
Received: 2014-07-04
Accepted: 2014-12-06

Analysis of the thermal behavior of gravure inks: comparing experimental results and numerical methods

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Abstract

Gravure inks are frequently applied in multiple layers as prints on packaging material. Besides giving some information about the product, the printed ink film can be used also for protection. The compound printed layer of different colored gravure inks (of equal thickness) plays an important role in protecting the product contained within the package from external atmospheric conditions. For example, heat transfer either from the outside or the inside of the package can be controlled by a properly designed ink film combination on the package. The color inks generally used are specialty white, standard yellow, magenta and cyan, together with black, applied consecutively. If these ink coatings are not long-lasting, or the system is not properly designed, this may lead to failure to protect the packaged product due to unwanted transfer. In the present investigation, the thermal properties of free films of different colored inks were measured individually and also in combination to assist in the design of appropriate ink layers on packaging leading to extended shelf-life for the product. The measured thermal properties are thermal conductivity, specific heat and the coefficient of linear expansion. Further, the thermal contact resistances of different color combinations, contact surface temperatures and thermal stress developed in the coating were determined using an algebraic method. A finite element method was also adopted for determining the contact surface temperature and thermal stresses developed. These numerical results were compared with the experimental findings. It was found that the heat transfer rate either from the package or from the outside will be much lower if the thicknesses of all the ink layers are equal. Also, it is proposed that if the coatings of inks are printed in the order of WKCMY, the protection of the product will be optimal.

Keywords: coating, coefficient of linear expansion, thermal conductivity, specific heat, contact thermal resistance

1. Introduction

Packaging is the most widely applied technique for enclosing or protecting products for distribution, storage, communication, sale and use. The materials used for packaging purposes are either metallic or non-metallic or a combination of both. Besides the structural packaging material itself, the use of gravure ink as a functional coating in the form of different colors of equal thickness applied onto packaging has an important role in protecting the product contained from the external atmosphere, with particular emphasis on preventing heat transfer either from the outside or from the inside of the package. Figure 1 shows the geometry of a package structure consisting of five different colored ink layers applied with equal thickness on the packaging base. The thicknesses of the different colored ink layers were made equal since these are printed using the CMYK model along with a white background using a gravure printing process.

To serve the purpose of protection, the package as well as the films of ink must be dimensionally stable under different ambient conditions during the life cycle of the product. So, the thermal and mechanical properties of the films, made of different colored inks (individual and combined ink films), will play a vital role in protective coatings (Paul, Naskar and Pal, 2011).

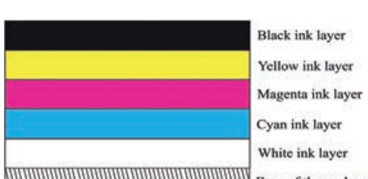

Figure 1: Geometry of a package structure printed with the CMYK model along with a white background (WCMYK)

2. Experimental procedures

2.1 Ink films and sample preparation

For the measurement of various thermal properties of gravure inks, free films of five different colored inks were made using a special technique developed earlier (Paul et al., 2002). The free films consist of individual as well as of combinations of different colored inks. Measurements of the thermal properties of the different colored inks are limited to thermal conductivity, specific heat and the coefficient of linear expansion. The thermal conductivity of different combined ink films was also measured to find out the contact thermal resistance of the ink combinations.

The sample preparation technique developed earlier (Paul et al., 2002) consists of two steps: (a) formation of uniform sample layers of the coatings, and (b) separation of the adherent films. A metal plate, of dimensions equal to or greater than that of the sample, was taken at first. A uniform layer of bee wax was coated onto the plate. A gravure ink layer was applied to the wax surface by roller. The ink layer was allowed to dry sufficiently before giving a second layer onto it. This layering process was continued only after the previous layer was fully dried and this process was continued until the required thickness was obtained. The ink film was carefully separated from the waxed metal plate by a sharp knife. This procedure leaves the film alone. Several samples of different thickness, each made up of cyan, magenta, yellow, black and white colored gravure inks, were used for the present studies. Combined ink films were made by applying ink layers on already made free films of ink.

2.2 Thermal conductivity

The thermal conductivity of the sample was measured as per ASTM C-177-45 (ASTM International, 1945). The sample was placed inside a guard plate heat conductivity unit (Model DTI-12, S. C. Dey & Co. Ltd., India) as shown in Figure 2. The sample was then heated over a certain temperature range at different ambient conditions and the temperatures on both sides of the sample were measured using thermocouples. The details of the measurement procedure are given by Paul et al. (2004a). For the measurement of the thermal conductivity of ink, about 150 data points, each of five different colors of different thickness ink films, were considered.

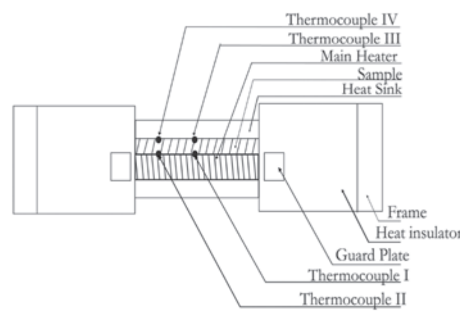

Figure 2: Schematic diagram for the measurement of thermal conductivity of different ink samples

2.3 Specific heat

The specific heat was also measured using the guard plate heat conductivity unit as shown in Figure 2. When one side of a sample is heated, the layer adjacent to the heater absorbs part of heat, leading to an increase in its own temperature. A part of the heat applied is lost by way of radiation from the surface and convection through the air. The remainder of the heat available passes into the adjacent layer, increasing the temperature of that layer. The instrument has been fabricated in such a way as to minimize the losses due to radiation and convection. Details of the measurement procedure are given in Paul et al. (2004a). In order to measure the specific heat of the samples, about 150 data points were taken into consideration for each of five different colored samples. The mean values of the specific heat of the samples are shown in Table 1.

2.4 Coefficient of linear expansion

The coefficients of linear expansion of free films of inks of different colors were measured using a resistance type strain gauge. Strain gauges having a gauge factor of 2.0 and an electrical resistance of 350 Ω were used. In order to measure the coefficient of linear expansion of the sample, the strain gauge was fixed on the surface of the sample. The strain gauge was fixed to the center of the sample using a thin layer of standard adhesive. The coefficient of linear expansion of the sample may be affected if the thickness of the adhesive is large. To compensate for this effect, a thick sample was taken for measurement and the experiment was repeated several times. The sample and strain gauge combination were placed in a closed chamber, the temperature of which was varied over a wide range from sub zero Celsius to room temperature by applying liquid nitrogen. The surface temperature of the sample was measured using a Hewlett Packard Data Acquisition System (Model 34970A) through a 'K type' thermocouple. The experimental arrangement for such measurement has been published by Paul, Naskar and Pal (2011). Details of the measurement procedure are given by Paul et al. (2004a). For the measurement of the coefficient of linear expansion of free films of five different colored ink samples, nearly 250 data points for each were used. The mean values thus obtained are shown in Table 1.

2.5 Contact thermal resistance

Thermal contact conductance is the measure of heat conduction between different solid bodies in thermal contact. The thermal contact conductance coefficient, h_c, is a property indicating the thermal conductivity, or ability to conduct heat, between two bodies in contact. The inverse of this property is called contact thermal resistance.

The contact thermal resistance R_C has been calculated using Equation 1 (Chapman, 1984; Holman, 1997) assuming that heat is flowing uniformly from layer 1 to layer 2 and that all the ink layers are isotropic in nature.

$$R_c = \frac{1}{h_c} = \left(\frac{(\theta_1 - \theta_2)A}{Q}\right) - \left(\frac{l_1}{K_1} + \frac{l_2}{K_2}\right) \qquad [1]$$

where h_c is the thermal conductance, l_1 the thickness of the hotter body in m, l_2 the thickness of the colder body in m, K_1 and K_2 the conductivities of layers 1 and 2, respectively, in $\mathrm{W\,m^{-1}\,K^{-1}}$, $(\theta_1 - \theta_2)$ the temperature difference between the upper and lower surfaces of the two layers in K, A the area of the layers in m^2, and Q the heat rate (power) in W.

The temperatures θ_1 and θ_2 were measured experimentally using the guard plate heat conductivity unit. In order to measure θ_1 and θ_2, a block of two different colored gravure ink layers was made by applying the second color on the top of first color. The color combination was selected according to Figure 1.

2.6 Contact surface temperature

2.6.1 Algebraic method for calculation of contact surface temperature

When two bodies are in contact, the temperature at the contacting surface is called contact surface temperature.

For a two layer system, assuming unit layer area, when the upper and lower surface temperatures are T_1 and T_3, and T_2 is the contact surface temperature, T_2 and T_3 can be calculated using Equations 2 and 3

$$T_2 = \frac{\left[T_1 + \left\{\left(l_1 / K_1 + R_c\right) / \left(l_2 / K_2\right)\right\} T_3\right]}{\left[\left\{\left(l_1 / K_1 + R_c\right) \;/\; \left(l_2 / K_2\right)\right\} \;+\; 1\right]} \qquad [2]$$

$$T_3 = T_1 - \{(Q/A)\,(R_c + l_1/K_1 + l_2/K_2)\} \qquad [3]$$

where R_c is the contact thermal resistance, and l_1 and l_2 the thicknesses of the two consecutive layers in m.

The assumption underlying this calculation is that there is no energy loss in the system. The contact thermal resistance of the system of coating layers WCMYK is calculated progressively using a successive two layer system. The values thus obtained are utilized to find the thermal stresses developed using an algebraic method.

2.6.2 Determination of contact surface temperature by finite element method

In order to calculate the contact surface temperature of the printed package with five layers of different inks, the differential Equation 4 (Akin, 1986) has been adopted for each individual layer and applied in the finite element method (FEM).

$$K\frac{\mathrm{d}^2T}{\mathrm{d}x^2} + Q = 0 \qquad [4]$$

The finite element solution for the above equation is used as in Equation 5

$$K^{e}T^{e} = Q^{e} \quad [5]$$

where $K^{e} = \frac{AK}{l}\begin{vmatrix} 1 & -1 \\ -1 & 1 \end{vmatrix}$ is the element stiffness matrix,

T^{e} the nodal temperatures in K, and Q^{e} the nodal heat flux in W per unit time.

Assembling layerwise homogeneous elements that have different conductivities, a non-homogeneous, one dimensional model has been considered. Steady state heat conduction through unit area is assumed for all elements. The system considered consists of six nodes and five elements, since the coating layers here are five, namely white, cyan, yellow, magenta, black ink layers, and the ink layers are isometric in nature. The values thus obtained were used to find out the thermal stresses developed.

2.7 Thermal stress

2.7.1 Definition

Thermal expansion or contraction cannot occur freely in all directions of any solid body because of geometry, external constraints or the existence of temperature gradients. So, stresses are produced. Such stresses caused by a temperature change are known as thermal stress. Thermal stress occurs as a result of a non-uniform distribution of temperature in different parts of the body.

2.7.2 Algebraic method for calculating thermal stress

In order to calculate thermal stress, Equation 6 was used

$$\sigma = E\alpha\Delta T \quad [6]$$

where σ is the stress in Pa, E the Young's modulus in Pa, α the coefficient of linear expansion, and ΔT the temperature difference between the two planar surfaces in K.

The modulus of elasticity (E) of free films of different colored inks was measured using a special technique developed earlier (Paul et al., 2004b). To validate the values obtained by the algebraic method, the finite element method was used.

2.7.3 Determination of thermal stress by finite element method

The finite element temperature distribution is expressed according to Equation 7 (Buchanan and Rudramoorthy, 2006) – see Figure 3,

$$T = [N]\ \{\ u(t)\ \} \quad [7]$$

where $[N]$ is the element stiffness matrix and $\{u(t)\}$ the nodal temperatures at time t.

The thermal load due to temperature difference can be expressed as in Equation 8

$$Q^{e} = \frac{EAl\alpha\Delta T}{(x_2 - x_1)}\begin{Bmatrix} -1 \\ +1 \end{Bmatrix} \quad [8]$$

where E is the effective Young's modulus of the coating in Pa, A the cross sectional area of the layer in m^2, l the layer thickness in m, and (x_2-x_1) the nodal distance in m.

The thickness l and nodal distance (x_2-x_1) are both on the same scale and in our case equal to 0.03 mm. For steady state and one dimensional heat conduction, the stress developed on a unit area of an individual layer can be expressed as in Equation 9.

$$\sigma = \frac{E}{(x_2 - x_1)}[-1 \;\; 1]\mathrm{u} - E\alpha\Delta T \qquad [9]$$

where σ is the stress on individual elements.

The corresponding nodal representation of the FEM is shown in Figure 3.

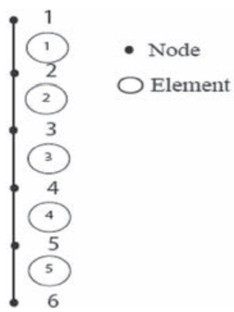

Figure 3: 1-D element model system of Figure 1

3. Results

Our measurements were conducted on free films of gravure inks of individual cyan, magenta, yellow, black and white, and different color ink layers in combinations of two colors, namely W-C, C-M, M-Y and Y-K. Table 1 shows the results (mean values) of the measurements of thermal properties of the samples as described in 2.2 , 2.3 and 2.4.

Table 1: Thermal properties of different gravure inks

Gravure ink film	Thermal conductivity ($\mathrm{W\,m^{-1}K^{-1}}$)	Specific heat ($\mathrm{kJ\,kg^{-1}K^{-1}}$)	Coefficient of linear expansion, α ($\mathrm{K^{-1}}$) $\cdot 10^{-6}$
Cyan ink	0.1307 ± 0.04	0.1028 ± 0.17	1.3217 ± 0.18
Magenta ink	0.1399 ± 0.01	0.1102 ± 0.18	1.4984 ± 0.11
Yellow ink	0.1391 ± 0.03	0.0885 ± 0.18	1.5631 ± 0.79
Black ink	0.2488 ± 0.05	0.1331 ±0.27	1.0695 ± 0.17
White ink	0.1537 ± 0.02	0.1203 ± 0.25	0.3628 ± 0.25

Figures 4–8 show the thermal conductivity as a function of temperature for the different samples under different atmospheric conditions, and Figures 9–13 show the variation of the coefficient of linear expansion with temperature under different atmospheric conditions.

Heat flow is directly related to the thermal conductivities of the bodies in contact. The conductivity of ink films in combination was measured in order to determine the contact (skin) thermal resistance (average calculated values are shown in Table 2).

Table 2: Contact thermal resistances of different colored ink film layers

Gravure ink film	Contact thermal resistances ($\mathrm{m^2K^{-1}W^{-1}}$)
White-Cyan	0.0191
Cyan-Magenta	0.0218
Magenta-Yellow	0.0139
Yellow-Black	0.0112

The measured values of E of different colored gravure inks are given in Appendix A. Table 3 shows the calculated values of thermal stress for the model (Figure 3) when heat is transferring from outside to inside of the package for a temperature difference of 40 °C.

Table 3: Thermal stress for our model when heat is transferring from outside to inside of the package

Individual color gravure ink	Thermal stress (MPa)	
	Algebraic	FEM
Layer 5 (K)	0.126	0.139
Layer 4 (Y)	0.704	0.716
Layer 3 (M)	1.623	1.629
Layer 2 (C)	0.870	0.872
Layer 1 (W)	0.157	0.157

Table 4 shows the calculated values of thermal stress for the model (Figure 3) when heat is transferring from inside to outside of the package for the same temperature difference as previously.

Table 4: Thermal stress for the model when heat is transferring from inside to outside of the package

Individual color gravure ink	Thermal stress (MPa)	
	Algebraic	FEM
Layer 1 (W)	0.157	1.233
Layer 2 (C)	0.870	1.949
Layer 3 (M)	1.623	2.706
Layer 4 (Y)	0.704	0.829
Layer 5 (K)	0.126	0.252

4. Analysis

Figures 4 and 5 show that the thermal conductivity of the white and cyan color ink layers decreases with temperature. The relative humidity of the atmosphere as well as the ambient temperature influence the thermal conductivity of both inks. For the white ink layer, the higher the ambient temperature and relative humidity, the greater the thermal conductivity. This implies that the heat conduction rate decreases with an increase in temperature.

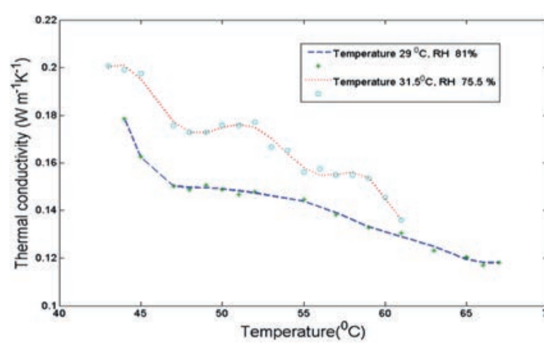

Figure 4: Variation of thermal conductivity of free film of white colored gravure ink with temperature at different atmospheric conditions

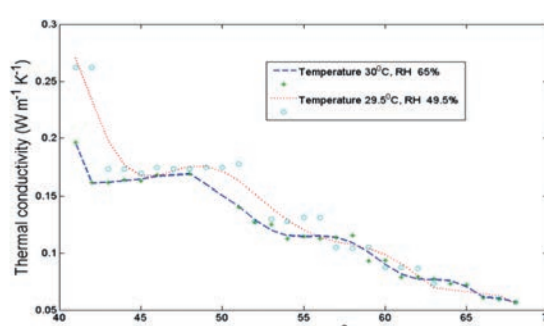

Figure 5: Variation of thermal conductivity of free film of cyan colored gravure ink with temperature at different atmospheric conditions

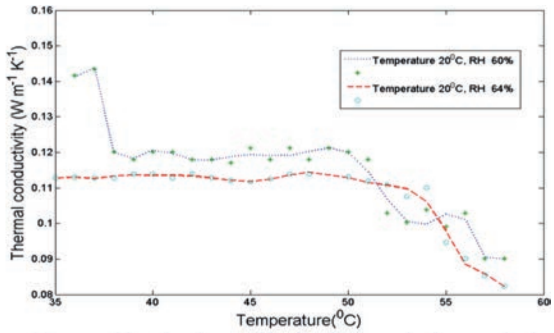

Figure 6: Variation of thermal conductivity of free film of magenta colored gravure ink with temperature at different atmospheric conditions

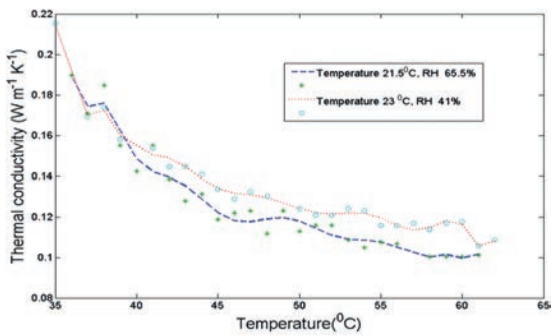

Figure 7: Variation of thermal conductivity of free film of yellow colored gravure ink with temperature at different atmospheric conditions

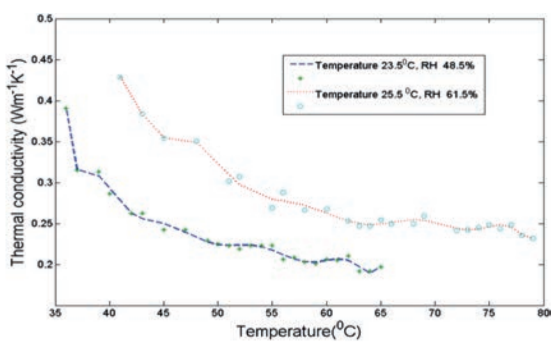

Figure 8: Variation of thermal conductivity of free film of black colored gravure ink with temperature at different atmospheric conditions

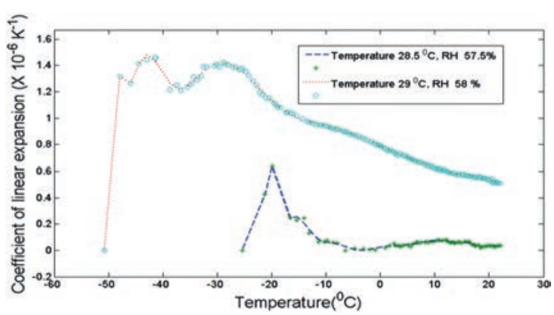

Figure 9: Variation of coefficient of linear expansion of free film of white colored gravure ink with temperature at different atmospheric conditions

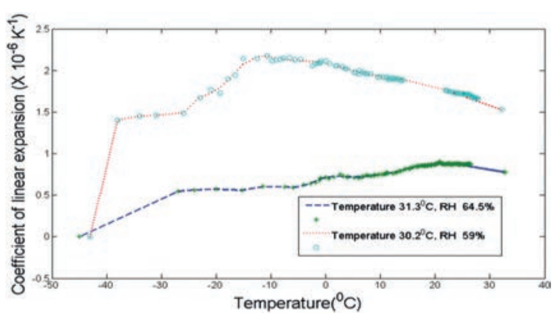

Figure 10: Variation of coefficient of linear expansion of free film of cyan colored gravure ink with temperature at different atmospheric conditions

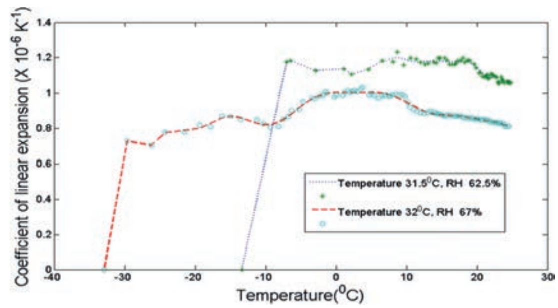

Figure 11: Variation of coefficient of linear expansion of free film of magenta colored gravure ink with temperature at different atmospheric conditions

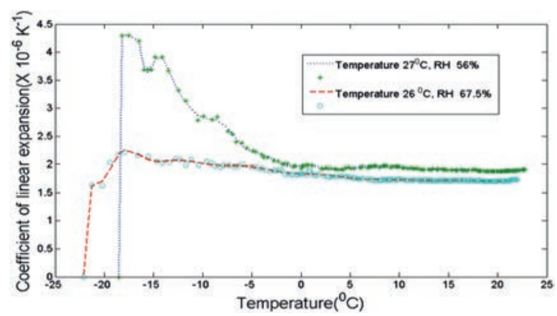

Figure 12: Variation of coefficient of linear expansion of free film of yellow colored gravure ink with temperature at different atmospheric conditions

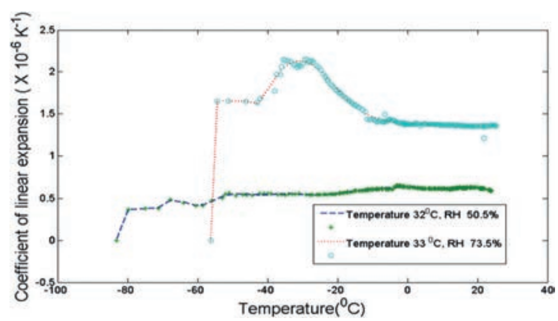

Figure 13: Variation of coefficient of linear expansion of free film of black colored gravure ink with temperature at different atmospheric conditions

From the thermal conductivity curve of the magenta ink film (Figure 6), it can be observed that the thermal conductivity remains more or less constant up to the temperature of 52 °C and decreases thereafter. The relative humidity also influences the thermal conductivity of the same. In this case, the effect of relative humidity is the reverse. The thermal conductivity decreases with an increase in relative humidity at least up to 52 °C as shown. This may be due to the type of pigment used in magenta ink. The pigment used in the magenta ink used is Barium 2B red toner (see Appendix B). This pigment has a tendency to release water soluble azo coupling groups as well as to absorb water. The strange behavior of the magenta ink film at different relative humidities and at lower temperature is due to the absorbed moisture by the pigment, which later evaporates.

For the yellow color ink film, the thermal conductivity decreases exponentially with an increase in temperature (Figure 7). For black ink film, the thermal conductivity decreases with the increase in temperature (Figure 8). The relative humidity and atmospheric temperature greatly influence the thermal conductivity of both inks. For black ink, it is obvious that the higher the temperature and relative humidity, the greater the thermal conductivity.

For the white ink film, the coefficient of linear expansion is at its maximum in the subzero range (i.e., −28 °C to −20 °C) and thereafter it decreases sharply with an increase in temperature (Figure 9). This may be due to the higher quantity of metallic oxide present in the white ink (see Appendix B) compared to the non-metallic organic part. As a result, the exchange of heat between the pigment and other material starts much earlier than when at a normal ambient temperature. For the cyan ink film, it can be observed that the coefficient of linear expansion is at its maximum at about −10 °C and decreases thereafter (Figure 10). The higher the ambient temperature and relative humidity, the lower the expansion coefficient of the cyan ink film. For magenta ink film, the expansion has a maximum at close to +7 °C for both ambient conditions (Figure 11). For both cyan and magenta ink films, it can be observed that the relative humidity and the temperature influence the coefficient of linear expansion. The higher the relative humidity and the ambient temperature, the lower the coefficient of expansion of magenta ink film within a normally applicable temperature range. For yellow ink film, it is seen that the coefficient of expansion decreases in the subzero (Celsius) range (i.e., −17 °C to −1 °C) and after that it remains constant in all ambient conditions (Figure 12). This may be due to the lower quantity of pigment present in comparison to binder (see Appendix B) in the yellow ink. It can also be observed that the ambient temperature influences the coefficient of linear expansion: the higher the ambient temperature, the higher the coefficient of linear expansion. For black ink film, it can be observed that coefficient of linear expansion increases with increasing temperature and has a maximum at a temperature range of −27 °C to −10 °C while remaining constant at higher temperatures. This may be due to the higher quantity of pigment present in the dried ink film in comparison to other materials such as binder, additives, etc. (see Appendix B). As a result, heat exchange between the pigment and the other materials starts much earlier than at 0 °C.

Tables 3 and 4 show the changes in numerical stress within the layer as heat is transferring from one layer to another. It can be seen that when heat is transferring from outside to inside as well as from inside to outside the maximum stress generation takes place in the magenta layer and the minimum in the black layer.

5. Conclusions

It has been found that the thermal conductivity of the black ink film is greater than the thermal conductivities of the free films of yellow, magenta and cyan color inks, which are more or less on the same level. The thermal conductivity of the white background layer is slightly higher than that of the free films of yellow, magenta and cyan colored inks. The coefficient of linear expansion of the free film of white ink is much lower. It has also been observed that the skin contact thermal resistance of a white-cyan combination and a cyan-magenta combination are more or less the same whereas the skin contact thermal resistance of a magenta-yellow ink combination and a yellow-black ink combination are lower than that of the previous two layers. This implies that the heat transfer either from the package or from the outside will be much lower if the thicknesses of the ink layers are equal. Again, the thermal stresses will be high at the contact point of a white and cyan layer due to differential thermal expansion of the two different layers. This may lead to cracking in the white layer due to its modulus of elasticity being smaller than that of cyan.

The thermal stress developed in a cyan layer is higher than that of a white layer. This is in accordance with the experimental findings.

With respect to the modulus of elasticity, ink films may be represented by M>C>Y>W>K. As per thermal stress analysis is concerned, when the package is subjected to external heating due to changes in ambient conditions, the thermal stress developed on the different ink films may be represented as M>C>Y>W>K.

Based on the measurements of thermal and elastic properties and on the numerical analysis, it is proposed that the coating of inks should be printed in the order of WKCMY to give better protection of the product by preventing heat transfer as well as failures of the coating layers.

White is used as a background layer to get the effect of the substrate as well as the effect of multicolor printing. Moreover, white ink uses titanium dioxide (anatase form) which has the property of preventing the passage of UV light. Regarding thermal conductivity, the ink films can be represented by K>W>M>Y>C and when considering the coefficient of linear expansion, the ink films may be represented by Y>M>C>K>W. This implies that expansion is the smallest on the white layer and black exhibits the least stress generation as per stress values. For these above reasons, the longevity of the packaging as well as the heat transfer rate from the outside will be optimal if the layers are printed in the order of WKCMY.

Finally, standard inks are considered as insulating material for cost reasons as well as a way to get proper superimposed color printing effect. Moreover, the white ink layer has the property of UV protection of the product since it is printed in solid form as a background layer on the package.

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Appendix A: Measuring the modulus of elasticity of free films of different colored gravure inks

Firstly, free films of different colored gravure inks have been prepared. Then a resistance type strain gauge having gauge factor of 2 is attached onto the surface of the ink film using standard adhesive. Thereafter the sample is hung on a horizontally fixed frame (Paul et al., 2004a) and it is subjected to different loads with the strain gauges connected to the data acquisition system to collect strain data at different loading conditions. The modulus of elasticity is then calculated.

Gravure ink sample	Modulus of elasticity (GPa)
Cyan ink	16.459
Magenta ink	27.075
Yellow ink	11.263
Black ink	2.946
White ink	10.803

Appendix B: Compositions of the different colored gravure inks

Liquid gravure ink contains three major ingredients together with smaller quantities of additives. The major ingredients are pigments (including dyestuff), binder, and solvent. The additives used consist of materials such as driers, plasticizer, wax, etc.

The composition of the gravure inks used in this work is as follows:

Black colored ink:

Ingredients	**% by weight**
Carbon black	30.0
Nitrocellulose	12.0
Dioctyl phthalate	7.0
Phenolic resin	1.0
Polyethylene wax	1.0
Ethanol	30.0
Ethyl acetate	19.0

The pigment present in the black colored gravure ink used is carbon black (CI Pigment Black 7 no. 77266) and the vehicles used in the ink are ethanol and ethyl acetate (Leach et al., 1988). The pigment/binder ratio in the gravure ink used is 2.308.

Magenta colored ink:

Ingredients	**% by weight**
Barium 2B red toner	9.0
Ethyl acetate	40.5
Venyl alcohol copolymer	10.0
n-propyl acetate	40.0
Polyethylene wax	0.5

The pigment present in the magenta colored gravure ink used is barium 2B red toner (CI Pigment Red 48.1) and the vehicles used in the ink are ethyl acetate and n-propyl acetate (Leach et al., 1988). The pigment/binder ratio in the gravure ink used is 0.9.

Yellow colored ink:

Ingredients	**% by weight**
Diarylide yellow	8.0
Alcohol soluble propionate	10.0
Acrylic resin	6.0
Ethanol	45.0
Ethyl acetate	30.0
Polyethylene wax	1.0

The pigment present in the yellow colored gravure ink used is diarylide yellow (CI Pigment Yellow 12) and the vehicles used in the ink are ethanol and ethyl acetate (Leach et al., 1988). The pigment/binder ratio in the gravure ink used is 0.5.

Cyan colored ink:

Ingredients	% by weight
Phthalocyanine blue	12.0
Alcohol soluble polyamide resin	13.0
Nitrocellulose	18.0
Dioctylphthalate	2.0
Antioxidant	0.5
Ethanol	40.0
Ethyl acetate	7.5
n-propyl acetate	5.0
Amide wax.	1.0
Polyethylene wax	1.0

The pigment present in the cyan colored gravure ink used is phthalocyanine blue (PBI 15.3) and the vehicles used in the ink are ethanol, ethyl acetate and n-propyl acetate (Leach et al., 1988). The pigment/binder ratio in the gravure ink used is 0.387.

White colored ink:

Ingredients	% by weight
Titanium dioxide	30.0
Nitrocellulose resin	11.0
Dioctyl phthalate	3.0
Polyurethane wax	8.0
Polyethylene wax	1.0
Erucamide	1.0
Ethanol	27.0
Ethyl acetate	16.0
Titanium acetyl acetonate (TAA)	3.0

The pigment present in the white colored gravure ink used is titanium dioxide (CI Pigment White 6) and the vehicles used in the ink are ethanol and ethyl acetate (Leach et al., 1988). The pigment/binder ratio in the gravure ink used is 2.727.

JPMTR 1439
DOI 10.14622/JPMTR-1439
UDC 655.1 : 763-035.4 (084)

Professional communication
Received: 2014-10-06
Accepted: 2015-02-04

Evaluation of misregister on multiple coated fine papers in sheet fed offset printing

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Abstract

Misregistration is one of the most common printing faults of wood free multiple coated fine papers in multicolor sheet-fed offset printing. Misregister significantly reduces print quality and leads to complaints to the paper manufacturer. Unfortunately it is often difficult to identify the cause of a misregister problem, because apart from the potential paper impacts, several printing machine and printing ink parameters may also have an effect. It would therefore be an advantage – especially for the paper manufacturer – to be able to determine and influence the factors leading to this problem. In practice a qualitative evaluation of misregister is frequently carried out using a printer's loupe, which is a quite subjective method and has the disadvantage of a rather low resolution. Evaluation of misregistrations using a light microscope allows higher resolution but is quite time consuming.
Therefore, a new offline measuring device for fast and objective evaluation of misregistrations was developed in the R&D department of Sappi Gratkorn. First results using this device show the expected relationships between misregistration and ratio of machine/cross direction fiber orientation, influence of grain direction and filler content of the base paper. Furthermore, misregister was found to be dependent on the amount of fountain solution as well as on the smoothness of the rubber blankets.

Keywords: misregister, sheetfed offset printing, machine/cross direction ratio, fiber orientation, filler content, fountain solution

1. Introduction and background

Conventional sheetfed offset printing still is the most important printing process in the print media world, because of its high quality, the flexibility in production and the comparatively low costs. The offset print process is prone to a variety of printing faults due to the complex interactions between paper, printing ink, fountain solution, rubber blanket and other printing machine components. One of the most frequent and most complex printing faults in sheetfed offset print is misregister. Falter (1980) states that misregister can lead to a completely different and totally undesired print appearance, which underlines the significance of correct registration.

The reasons for misregister are versatile and often not easy to determine or to identify because of the inhomogeneous nature of paper, the different paper production technologies and differences in the printing process itself. Nonetheless it is clear that the main causes are to be found either in the printing machine or in the paper used. In the past significant research was carried out concerning misregistration problems, but only a few parameters allowing a reduction of the occurrence of misregister were identified. One reason for this outcome is that often only one influencing factor was considered. Furthermore, the impacts from the side of paper manufacturing and from the printing process together were rarely compared in relation to misregister. The following list shows some of the possible causes for misregistration resulting from the paper properties or from the printing process settings:

- Disadvantageous ratio of machine direction (MD) and cross direction (CD), i.e. fiber orientation or tensile stiffness orientation (Loewen and Foulger, 2002; Machattie, Paavola and Shakespeare, 2010; Odell and Pakarinen, 2001),
- Dimensional instability, high wet expansion and weakened fibrous structure of paper due to the intake of fountain solution and/or high moisture content (Aspler, 1993; Boström, 2001; Horand, 1986; Niskanen, Kuskowski and Bronkhotst, 1997; Uesaka and Qi, 1994),

- Dimensional instability resulting from the release of frozen tensions or shrinkage induced by drying and calendering (Brecht, Knittweis and Schmidt, 1971; Falter, 1980; Laurell Lyne, Fellers and Kolseth, 1996; Praast, Göttsching, 1995; Uesaka, 1991),
- Electrostatic charge of the paper (Falter, 1980),
- Cross cutter rhythm resulting in variations in thickness, smoothness, MD/CD-ratio, ink penetration, elongation or fiber orientation (Falter, 1980; Horand, 1986),
- High elastic/plastic elongation behavior of the paper (Horand, 1986; Kipphan, 2001; Weber, 1934),
- Incorrect manufacturing of the printing plate and failure during the copying and development process (Kipphan, 2001),
- Defective mounting of the printing plate; inaccurate function of grippers (Kipphan, 2001),
- Too high linear load in the printing nip (Falter, 1980; Kettinger and von Lospichl, 1975),
- High pull-off forces of paper from rubber blanket caused by high tack/viscosity inks and/or tack/viscosity increase of the inks during ink oil absorption (Bluvol et al., 2003; Gane, Matthews and Schoelkopf., 2000; Rousu et al., 2000; Resch and Bauer, 2007; Triantafillopoulos, Lee and Ave'Lallemant, 1996),
- High pull-off forces caused by very smooth paper and/or rubber blanket surfaces (Kawashima and Bousfield, 2008; Mattila and Passoja, 2006).

A severe limitation regarding improvements in the registration behavior of papers is the correct quantitative measurement. Very often only a qualitative evaluation using a printing loupe or a light microscope is carried out. Results using a printing loupe are too inexact due to the low resolution of the loupe and light microscopic methods are highly time consuming. Commercial register measuring systems are available in the market (e.g. LUCHS III or AUTOLUCHS system by PITSID[1] or PressAssess system by Technology Coaching BvbA[2]), which are mainly targeted at the printing industry and are therefore not widely used within the paper industry. Also these commercial systems do not allow access to the source code of the software, which makes these systems quite inflexible.

Therefore, a register measuring device was developed in the R&D department at Sappi Gratkorn in order to allow the systematic evaluation of paper related parameters causing misregister problems. The aim is the prediction of the registration behavior of papers based on paper parameters measured in paper production. This article presents the developed register measuring device and shows some initial results from the application in the evaluation of misregister depending on some basic paper properties (e.g. grain direction, filler content) and on some printing process variables (e.g. smoothness of rubber blanket, fountain solution amount).

2. Methods

In this section the hard- and software of newly developed register measurement system is presented. Additionally an overview of the commercial printing trials and the printed paper samples is given.

2.1 Hard- and software

The offline measuring device (see Figure 1) consists of a CCD camera, a macro object lens and a lighting device. The color camera (UI-2280-SE-C by IDS[3]) has a resolution of 2448 × 2050 pixel and a sensor area of 8.446 × 7.066 mm. The focal distance of the object lens (MeVis-C1.6/25 by QIOPTIQ[4]) is 25 mm and needs an operating distance of at least 30 mm. The lighting device (ACIS-35/35 white, 24VDC by Volpi[5]) illuminates an area of 35 × 35 mm.

Figure 1: Hardware of register measuring device

The register measuring software and the user interface are programmed in MATLAB and allow an easy selection of the regions of interest and an automatic calculation of the amount of misregistration.

2.2 Measuring principle

Instead of print marks, measuring fields with full tone squares (3 × 3 mm) were used (see Figure 2). Each full tone square stands for the corresponding printing unit, such as the black square in the center of Figure 2, which represents the first printing unit (identifiable by the number). The distance between the centers of each field in horizontal as well as vertical direction is 4 mm.

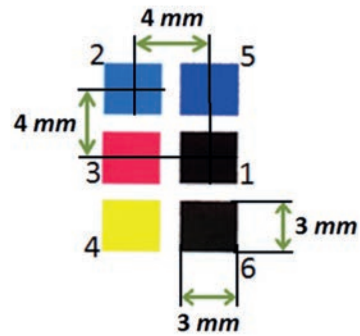

Figure 2: Measuring field with full tone squares and the horizontal and vertical distances of 4 mm to the reference square in the center

The black full tone square of the first print unit is taken as the reference because the sheet is not subjected to any significant strain before being released from the first rubber blanket.

The original distances from each of the squares to the square of the first print unit (the reference) is known from the design of the printing plate (i.e. 4 mm). These known distances are called "reference distances". After printing the measuring fields are imaged using the camera system and the so called "actual distances" are determined automatically. The differences between the "reference distances" and the "actual distances" are taken as a measure of misregistration. The procedure is repeated for each color represented by the squares in the measuring field. The principle is quite similar to the determination of misregister using standard printing marks but determination is easier as the colors are not printed on top of each other.

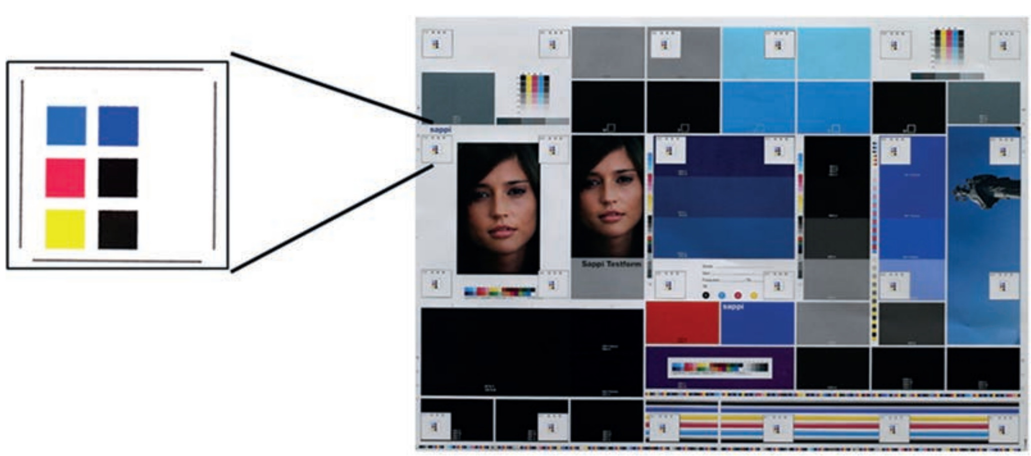

Figure 3: 63 × 88 cm standard print test form with the 24 integrated measuring fields

In the evaluation of misregister, the system measures two distances [µm] for each printed color for each of the 24 measuring fields representing misregister in the print direction and in the cross direction (i.e. 240 single values per printed sheet, see Figure 3). In order to facilitate the interpretation of the results, the following procedure is applied to arrive at a single value per sheet: The maximum and minimum values in printing and cross direction for each color in the 24 measuring fields on a sheet is determined by the software. The absolute difference of this maximum and minimum value in printing and cross direction for each color is calculated. Then the mean absolute difference for all colors in printing and cross direction is determined. Applying the Pythagorean theorem the so called "misregister value [µm]" for the whole sheet is computed from these two absolute mean values.

2.3 Print trials

In order to evaluate the developed measurement system a series of print trials were carried out where parameters known or expected to have a clear effect on misregister were varied. The print trials were targeted at two areas: The first area concerned paper related parameters and some important paper properties were varied. In the second area, the influence of two important printing process related parameters was evaluated.

In all trials, glossy or silk wood-free coated papers with a grammage of 115 or 135 g/m² were used (see Table 1). The print speed for all trials was 8000 sheets per hour. The used printing inks were manufactured by Flint Group.[6] During the trials, five consecutive paper samples were taken. These five sheets were evaluated in a climate room (23 °C, 50 % relative humidity) after one day storage, using the procedure described in 2.2. The mean value and the standard deviation of the five "misregister values" were calculated.

2.3.1 Paper quality related trials

The influence of grain direction (long grain or short grain), MD/CD ratio of tensile strength (MD/CD-tensile ratio) and filler content of the base paper on misregistration was investigated. Also rolls taken from the center (CR) and the edge (ER) of the web coming from the paper machine were evaluated. The sheet size of the paper in these trials was 63 × 88 cm and the trials were carried out on a Heidelberg Speedmaster XL 105-8-P (see Table 1). The rubber blankets used during the paper quality related trials were manufactured by Birkan[7] (DotMaster RS, smoothness 1.3 µm).

2.3.2 Print process related trials

Investigations concerning the effect of the smoothness of the rubber blanket (RB) and the amount of fountain solution (FS) on misregistration were carried out. The used rubber blankets were manufactured by Birkan (DotMaster RS, smoothness 1.3 µm) and Flint Group (dayGraphica 3000, smoothness 0.5 µm). During the investigation concerning fountain solution, merely the rubber blankets from Flint Group were used. The sheet size of the paper samples was 50 × 70 cm and the trials were run on a Heidelberg Speedmaster XL 105-5+L (see Table 1).

Table 1: List of printed paper samples and print process adjustments

Printed Paper, grammage [g/m²] and sheet size [cm]	**Grain direction**	**Varied parameter**	**Printing machine; Heidelberg Speedmaster**
Paper quality related trials			
Silk 135; 63 × 88	Long grain	MD/CD-ratio = 2.0	XL 105-8-P
Silk 135; 63 × 88	Long grain	MD/CD-ratio = 2.4	XL 105-8-P
Silk 135; 63 × 88	Long grain	MD/CD-ratio = 2.8	XL 105-8-P
Silk 135; 63 × 88	Short grain	Center Roll	XL 105-8-P
Silk 135; 63 × 88	Long grain	Center Roll	XL 105-8-P
Silk 135; 63 × 88	Short grain	Edge Roll	XL 105-8-P
Silk 135; 63 × 88	Long grain	Edge Roll	XL 105-8-P
Gloss 135; 63 × 88	Long grain	Filler content = 16.0 %	XL 105-8-P
Gloss 135; 63 × 88	Long grain	Filler content = 21.9 %	XL 105-8-P
Gloss 135; 63 × 88	Long grain	Filler content = 32.6 %	XL 105-8-P
Print process related trials			
Gloss 135; 50 × 70	Long grain	RB 0.5 and 1.3 µm	XL 105-5+L
Silk 115; 50 × 70	Long grain	RB 0.5 and 1.3 µm	XL 105-5+L
Gloss 135; 50 × 70	Short grain	FS standard and increased amount	XL 105-5+L
Silk 135; 50 × 70	Long grain	FS standard and increased amount	XL 105-5+L
Gloss 135; 50 × 70	Long grain	FS standard and increased amount	XL 105-5+L
Silk 135; 50 × 70	Long grain	FS standard and increased amount	XL 105-5+L
Gloss 135; 50 × 70	Long grain	FS standard and increased amount	XL 105-5+L
Silk 135; 50 × 70	Long grain	FS standard and increased amount	XL 105-5+L

3. Results and discussion

3.1 MD/CD-tensile ratio and grain direction

Figure 4 shows the effect of a change in MD/CD-tensile ratio on the misregister value. Three paper samples with distinctly different MD/CD-tensile ratio of 2.0, 2.4 and 2.8 were manufactured. The samples were printed in long grain. As expected the sample with the highest MD/CD-tensile ratio clearly showed an increase in misregistration compared to the samples with the lower MD/CD-tensile ratios.

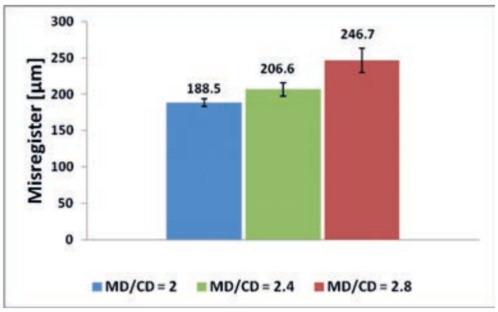

Figure 4: Influence of MD/CD-tensile ratio on misregister; the error bars indicate the standard deviation of the misregister measurements

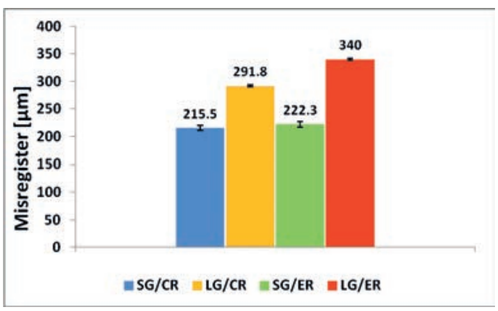

Figure 5: Impact of grain direction and paper sheets from the center or edge of the roll on misregister (SG/CR means short grain center roll, LG/CR long grain center roll, SG/ER short grain edge roll and LG/ER means long grain edge roll); the error bars indicate the standard deviation of the misregister measurements

The influence of grain direction and of the position where the sheets were taken from the paper machine web (center and edge rolls) on misregister are presented in Figure 5. Two long grain (LG) and two short grain (SG) paper samples, taken either from the center (center roll, CR) and edge (edge roll, ER) of the paper web from the same mother reel were compared. While the grain direction had the expected significant effect (misregister increased by 35 % for the center roll and by 53 % for the edge roll for long grain compared to short grain samples), the effect of the position in the paper machine web (edge roll compared to center roll) on misregister was insignificant for the short grain samples and showed a 16 % increase for the long grain samples.

3.2 Filler content

Three paper samples with varying filler contents were produced on the same paper machine and with the same coat weight and surface qualities. All paper samples were printed in long grain. A clear linear correlation between filler content and misregister can be observed in Figure 6. According to Fairchild (1992) and Li, Collis and Pelton (2002), paper sheets with higher filler content show lower stability (for instance tensile strength or breaking length) which means higher elongation at same load. And this seems to cause higher misregistration.

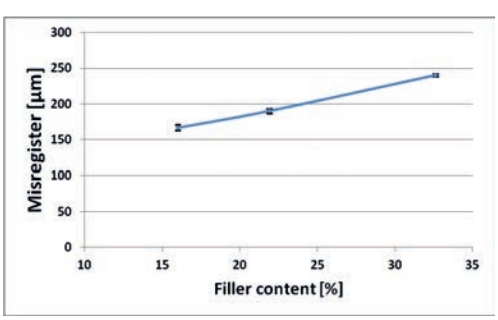

Figure 6: Impact of filler content on misregistration; the error bars indicate the standard deviation of the misregister measurements

3.3 Smoothness of the rubber blanket

Two rubber blankets with different smoothness levels of 0.5 μm (dayGraphica 3000 manufactured by FlintGroup) and 1.3 μm (DotMaster RS manufactured by Birkan) were used during the print trial. The rubber blankets had the same properties regarding thickness, micro hardness, elongation and compressibility. Both paper samples were printed in long grain. Figure 7 shows an increase of misregistration at approximately 20 % for the smoother blanket compared to the rougher blanket. It seems that smoother rubber blanket surfaces create higher pull-off forces which cause higher misregister.

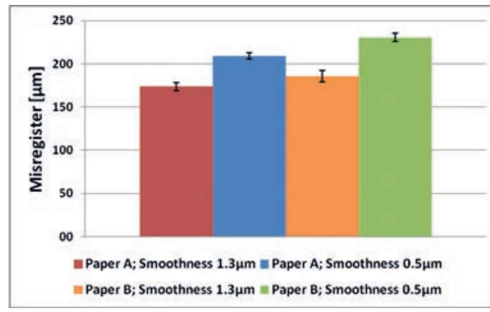

Figure 7: Impact of a smoother rubber blanket on misregistration; the error bars indicate the standard deviation of the misregister measurements

3.4 Amount of fountain solution

Six different glossy and silk WFC paper samples were printed in this trial first using the standard amount of fountain solution and then a 20 % increased feed rate. It was unfortunately not possible to determine the increase in the amount of fountain solution that actually came in contact with the paper. Except the first sample, all papers were printed in long grain. On average, misregister increased by 8.5 % for the higher amount of fountain solution, but the increase also depended on the type of paper sample with some samples not showing a significant increase. This rather low influence of the increased amount of fountain solution could also be explained by the decreased tack of the ink. Figure 8 shows that a higher amount of fountain solution increases the level of misregistration.

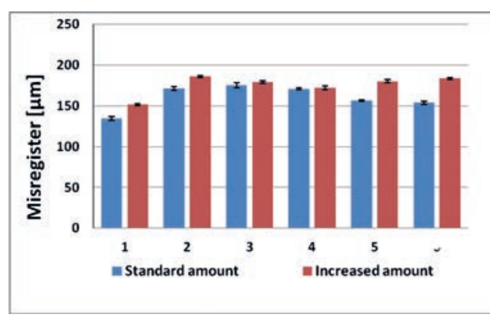

Figure 8: Impact of different amounts of fountain solution on misregistration; the error bars indicate the standard deviation of the misregister measurements

4. Conclusion

The developed measurement system proved to be a valuable tool in the systematic investigation of misregister problems. The results of the paper related trials shows the expected influence of the grain direction with lower misregistration for short grain paper sheets. A modification of the MD/CD-tensile ratio from 2 to 2.8 caused 30 % more misregistration. A difference between center and edge roll paper sheets, particularly in the case of long grain was observed. Misregistration was high when long grain sheets were cut from an edge roll. The reason is the well-known fact, that the edges of a paper web show lower tensile strength and higher elongation in CD-direction. Filler content in base paper and misregister show a clear linear correlation.

In the print related trials the use of smoother blankets clearly resulted in higher misregister values. More force seems to be needed to separate the paper sheet from the blanket when the blanket is smoother (Kawashima and Bousfield, 2008). The increase in the amount of fountain solution on misregistration was lower than expected, presumably to a decreased tack of the ink caused by higher emulsification (Fröberg et al., 2000; and Xiang and Bousfield, 1999).

Acknowledgements

The author thanks Sappi Fine Paper Europe for financial support and Anton Albert for carrying out the printing trials.

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Notes

[1] http://www.pitsidleipzig.com
[2] http://www.tcbvba.be
[3] http://www.ids-imaging.de
[4] http://www.qioptiq.de
[5] http://www.volpi.ch
[6] http://www.flintgrp.com/
[7] http://www.birkan.de/

Topicalities

Edited by Markéta Držková

Contents

News & more

On the way to drupa 2016 and beyond

A three-year cycle announced for drupa after 2016

As the answer to the radical changes in the entire print process chain, the drupa committee decided this February that drupa will switch to a three-year cycle, running in May of 2019, 2022 and 2025 in Düsseldorf. Driven by the Internet and digital technologies, new applications and solutions are developing, opening up new fields of business. At the same time, innovative technologies, such as 3D printing, printed electronics and functional printing, are getting more attention. Therefore, the drupa, regarded as the world's leading trade fair for print and cross-media solutions, shortens the cycle to bring a timely overview of the technology and an inspiration to use new business models and solutions.

dip – drupa innovation park 2016

Intended to be the global platform for innovation presenting technology and business solutions for the future, six theme parks of drupa 2016 will display current trends and topics along with business cases associated with process-oriented print and publishing solutions. Covering an area of more than 3000 square meters, once again the drupa innovation park can be found in Hall 7.0, presenting young companies and start-ups as well as global players with forward looking solutions and applications. The industry will have an opportunity to acquire insights into the technologies of the future essential for strategic business decisions.

Park on Multichannel Publishing & Marketing Solutions covers topics such as management of cross-media content/assets, web & app publishing, database publishing or marketing and brand management solutions. Also potential applications and trends like augmented reality, near field communication applications or customised mass production are in the focus. Web-to-Media & E-Commerce park offers solutions for web-to-publish or web-to-print, e-commerce & shop platforms, cloud publishing and web editors for design/print and HTML 5. Visitors to Process Optimization & Automation area can look for solutions and innovation on management information systems, enterprise resource planning, print automation with JDF/JMF, workflow management from pre-press to finishing, process and quality control systems, industrial robots and automation technologies. In case of the park on Added Value in Print, the focus is on finishing, further development and the advanced added-value of print products, including innovative substrates, new finishing methods, packaging, labelling printing and displays, green printing and secure printing. Modern printing and process technologies will be presented in Innovations in Printing Technologies theme park and visitors will find there applications for functional printing, printed electronics, 3D printing, solutions for prototyping, visualisation and workflow. Finally, new business concepts and models, strategic co-operation and marketing platforms, finance concepts and franchising and licence models are the subject of Business Models park.

Smithers Pira Industry Insights 2014–15

Within the Industry Insight series, Smithers Pira's expert team identified low-migration ink technology, digital print in packaging applications and 3D printing as the year's hot topics for print industry. Digital print in packaging applications is highlighted for packaging industry as well; further, brand owner perspectives on sustainability and paperboard luxury packaging are covered.

The latter one is in focus also in case of Paper Industry Insight, accompanied by global specialty paper trends and biorefining in the pulp and paper industry. The 2015 State of the Industry published in December 2014 for Print, Packaging and Paper, respectively, is included.

New inkjet printheads

The Samba technology has a single-head print width of 43 mm and due to its scalable design can be configured to make a print bar of any width. The stitching is simplified thanks to parallelogram design of the nozzle plate, resulting in a very narrow high-resolution printbar.

FUJIFILM Dimatix, Inc. places extra emphasis on dot placement accuracy, channel-to-channel uniformity, low cross talk and high frequency/high productivity. The new Samba drop-on-demand inkjet printheads have 2,048 individually addressable nozzles, delivering 1200 dpi native resolution

(600 dpi in redundant mode) and a native ink drop size of 2.4 pl.

A wide range of fluids including UV curable and aqueous inks can be printed in applications such as high quality commercial print, labels, packaging and textiles. Two advanced jetting technologies provide versatility without affecting device productivity. RediJet™ shown at drupa 2012 encompasses continuous ink recirculation directly behind the nozzle, nozzle plate innovations and waveforms tailored to specific fluids, thus reducing time to print and ink waste, as well as increasing reliability. With VersaDrop technology, the Samba printhead is designed to eject adjustable drop sizes from 2.4 to 13.2 pl through the activation of the piezoelectric element with waveform pulses of varying amplitude.

Display analysis & certification

The recognized Ugra Display Analysis and Certification Tool (UDACT) is commonly used for certifying calibrated displays for soft-proofing and is based on ISO 12646 and the colour patches of the widely accepted Ugra/Fogra Media Wedge. In addition to the 72 Media Wedge patches, the UDACT also measures the calibration and the grey balance precision. The tool implements a ranking for the use of the displays – recommended for high quality commercial printing, newspaper printing or simple layout.

ugra
Display Analysis and Certification Tool

A monitor can be tested with different measuring devices, including Eizo-Swing. First, colours are displayed in the middle of the display, measured and then evaluated. For a uniformity test, the homogeneity of the monitor is determined from the values measured at nine positions. The ambient light tool enables to measure conditions around a display. The results are shown on the screen and can be saved as PDF.

Since 2010, UDACT version 2 is available, with 2.3.1 being the latest. Recently, BenQ PG2401PT became the first Ugra officially certified display.

New edition of the established layout application

The 2015 edition of QuarkXPress by Quark Software Inc. is announced to be available soon. The new features reflect the top 10 most user-requested enhancements and features for print and digital production, as well as designer-controlled automation, with 64-bit architecture and PDF output conforming to the PDF/X-4 standard on the top of the list.

Other features the users watched for include PDF opening after export, more than 4× larger page sizes and definition of custom paper sizes, fixed layout interactive eBooks, relinking of images in the Usage Dialogue, collecting for Output and Usage for complete Project, Table Styles, and Format Painter. Platform-specific changes are represented by user-definable shortcut keys and Yosemite OS X Support for Mac, as well as Tool Palette, Measurement Palette and Palette Group docking on Windows.

Besides already established functions like style sheets, master pages, indexes, TOCs, shared content, conditional styles and callouts, QuarkXPress 2015 offers additional automation possibilities comprising automatic footnotes and endnotes, faster table tool for Excel integration with table styles, and text variables for use in reoccurring fields like running headers.

QuarkXPress 2015 enables the creation of HTML5 fixed layout eBooks with app-like interactivity. The fixed layout eBook format (ePub3 or Amazon's KF8) displays pixel-perfect layouts without the need to create native apps, while interactive enrichments such as scrollable areas, page flips, animations and more still can be added.

QX QUARKXPRESS 2015

QuarkXPress 2015 is available as a perpetual license, not as a subscription-based one.

Digital Ink Troubleshooting Guide

Sun Chemical has launched a new online troubleshooting guide designed to help wide format digital ink customers resolve common technical issues that can arise during printer operation. The freely accessible website summarizes a number of typical problems and provides recommendations on how to deal with a particular challenge.

The troubleshooting guide covers head strikes, banding, color, print quality and printer operation issues, and offers everyday tips. The instant availability of an online guide should help to keep the printing equipment running smoothly and limit downtime.

SunChemical®
a member of the DIC group

Digital Ink Troubleshooting Guide builds on the established Ink Troubleshooting Guide which Sun Chemical recently enhanced with a mobile application. The app for mobile devices is available on Google Play and the Apple App Store and provides characteristics and solutions for common issues in flexographic, sheetfed, gravure, paper packaging, and/or energy curable printing. After choosing the printing process, the app uses both photos and defect terms (dot gain, feathering, ghosting, piling, stripping, scumming, tinting, comets, pinholes, blister, hickeys, fisheyes, ink smearing, misting, linting, plate blinding, and many more) to help the printer identify which technical problem they are facing and then read the solution provided by Sun Chemical.

Bookshelf

Handbook of Digital Imaging

The handbook with more than 50 contributors both from academia and industry across the world aims to provide a comprehensive overview and practical analysis of the imaging science from image acquisition and storage through processing to print or display. The content exceeding 1,800 pages is organized into three volumes – Image Capture and Storage, Image Display and Reproduction, and Imaging System Applications. Volume 1 starts with the comparison of digital and analog imaging. Next, digital imaging optics and sensors are described, followed by the introduction to image processing and chapters on digital cameras color reproduction, compression and storage file formats, and image quality concepts. Finally, image systems simulation, multispectral imaging and glare issues are discussed.

Topics of Volume 2 include image display and projection, hardcopy technology, halftoning and physical evaluation, and models for halftone reproduction. First chapters bring overview of various display technologies (liquid crystal displays, plasma display panels, liquid crystal on silicon displays, displays based on organic light-emitting diodes, field emission displays, surface-conduction electron-emitter displays, electroluminescent displays and touch panel displays), and also describes digital micromirror devices and digital light processing. Hardcopy technologies comprise electrophotography and inkjet, with related toner and ink technologies, respectively, and fusing concepts. The rest of the second volume is dedicated to halftones both from a technological and theoretical perspective, covering basics of tone reproduction, digital halftones, and measurement of color halftone quality, as well as fundamentals of optics and radiometry, basic and advanced models for color halftone reproduction and digital imaging, and two-flux and multiflux matrix models for colored surfaces.

Imaging system applications in Volume 3 are divided to media, remote and medical and forensic imaging. Several chapters on media imaging deals e.g. with single-sensor imaging devices, Blu-ray, internet movies, various TV technologies services, including delivery from the cloud. After introducing remote imaging for planetary and astrophysical missions, the last part reports on imaging for diagnosis and robotic surgery, volumetric medical imaging, digital microscopy, and digital photo forensics.

Michael Kriss and his team (Pochi Yeh, Claire Gu, Li Yang, Gianluigi Ciocca, Rajesh Kumar, and Randall Friedl) have oriented the coverage on engineers and designers in the high-tech imaging, image processing and display industries – including photography, cinematography, mobile imaging and display, medical imaging and display, printing, copying and scanning, telecommunications, forensic science, remote sensing and surveillance. As a secondary audience, academics at universities and research institutions are identified, engaged in the areas of image processing, image understanding, computational intelligence in imaging, colour science and technology, image analysis, machine vision and visualization. Besides the print edition, the Handbook of Digital Imaging is also available in Wiley Online Library.

Handbook of Digital Imaging
Editor: Michael Kriss
Publisher: Wiley
1st ed., February 2015
ISBN: 978-0-470-51059-9
1824 pages
Hardcover

Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing

Authors: Ian Gibson, David Rosen, Brent Stucker

Publisher: Springer
2nd ed., 2015
ISBN: 978-1493921126
498 pages, 224 images
Hardcover
Also as an eBook

This updated and extended edition first provides a basic overview of additive manufacturing (AM) principles and processes and then offers a detailed overview of the most widely used AM technologies. Description of printing processes was split into two chapters on material jetting and on binder jetting. Low-cost AM systems are shortly introduced as well. Chapters in the last part should help to choose the right technology and use it properly for particular purpose, from the design and software issues to post-processing. Special applications such as micro-scale manufacturing, medical applications, aerospace, and rapid manufacturing are also discussed, as well as Additive Manufacturing File Format and AM standardization. However, as in the case of 1st edition, there are reader complaints about book quality, reporting both technical and editorial shortcomings.

Mutative Media: Communication Technologies and Power Relations in the Past, Present, and Futures

Authors: James A. Dator, John A. Sweeney, Aubrey M. Yee

Publisher: Springer
2015
ISBN: 978-3319078083
208 pages, 19 images
Hardcover
Also as an eBook

This book covers the history of each era of communication. After explanation of the key terms, the authors describe the appearance of human language and speech, and then review research on the emergence of signs, symbols, and eventually writing. Next, the impact of the printing press in Europe, the

Ink Jet Textile Printing

The purpose of the book published within the Woodhead Publishing Series in Textiles as No. 161 was to provide an introduction to the emerging technology of inkjet printing onto textiles, considering scientific research into this area as well as real-world utilization of this technology. The Ink Jet Textile Printing book is aimed at diverse reader groups – tertiary level students, educators seeking to update their knowledge, industry professionals and government opinion and policy makers researching new technologies.

Textile printing belongs to industries strongly influenced by recent expansion of inkjet printing, raising the need to understand its principles and to give examples of its successful application to textile products. The author tracks individual process steps of textile inkjet printing, giving brief overview on related theoretical background, functional principles and materials, and discusses impact of this technology along the printed textiles supply chain. After introductory chapters summarizing theoretical foundations of inkjet printing traced deep into history and its development for textiles, various aspects of the textile inkjet printing process are covered. Cloth as a substrate and its pre-treatment for inkjet printing, colour management issues, inkjet print heads and inks for digital printing, along with fixing and washing of inkjet-printed textiles, are described. Sublimation and transfer printing on textiles are included too. Concluding chapters discuss effects of inkjet on the textile printing industry – designers, manufacturers, wholesalers, and retailers, and further opportunities it brings.

Ink Jet Textile Printing
Author: Christina Cie
Publisher: Woodhead Publishing
1st ed., February 2015
ISBN: 978-0-85709-230-4
202 pages
Hardcover
Available also as an eBook

First 5.0: Flexographic Image Reproduction Specifications & Tolerances

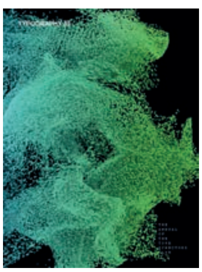
This comprehensive set of specifications, guidelines and tutorials, contributed by numerous experts in the field, is designed to provide all members of the flexographic supply chain with the technical information necessary to produce high-quality and consistent print results, pressrun after pressrun. Fifth edition of the compendium is announced as a dramatic upgrade to the previous version. Where applicable, First 5.0 conforms to international standards and includes technical updates to maintain relevancy with the evolving technology. There are new appendices on creative brief and style guide, expanded gamut, and 2D codes (QR, Data Matrix and Snap Tags) and a new subsection – Optimizing the process color gamut.

First 5.0: Flexographic Image Reproduction Specifications & Tolerances
Publisher: Flexographic Technical Association, Inc.
5th ed., 2014
ISBN: 978-0-9894374-4-8
404 pages
Paperback
Available also as an eBook

Typography 35

Typography, the annual publication devoted to the art of type, is a showcase of the year's best typographic work in print and on screen in advertising, communications, education, marketing, and publishing.

Each year, the Type Directors Club selects a prominent design studio or designer to curate the latest Typography book and select the winners of their annual typography competition. Tremendous creative freedom is given to each studio, allowing the annual to evolve dramatically with each new publication. Typography 35 presents the finest work in the field for 2013 and is designed by American graphic designer, creative director, and educator Brian Collins, who was the chief creative officer of the Brand Innovation Group, Ogilvy & Mather, from 1998 to 2007. Winning designs were selected from approximately 2,300 international submissions to the annual Type Directors Club competition and as usually are representing a wide range of categories in diverse fields, including books, magazines, corporate branding, logos, stationery, annual reports, video and web graphics, and posters.



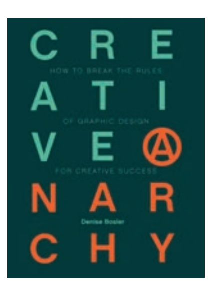
Typography 35
Publisher: Harper Design
January 2015
ISBN: 978-0-06-211289-7
368 pages
Hardcover
Available also as an eBook

Creative Anarchy: How to Break the Rules of Graphic Design for Creative Success

Creative Anarchy book explains and explores both rule-following and rule-breaking design and brings exercises to help clarify rule breaking methods. In contrast to the title, Part 1 of the Creative Anarchy says Learn the Rules. These 10 essential design rules claim that message is commander, the computer is only a tool, remember the basics, type is everything, color matters, it's hip to be square, use a grid, make things the same—or different, leave your ego at the door, and finally, break a rule or two. Part 2, Break the Rules, can be found when flipping the book over and contains chapters devoted to advertising, branding, posters, publication design, promotions and invitations, packaging and interactive design.

A word from the author, Denise Bosler: "The ability to push boundaries is a respected quality. It shows you are willing to go beyond the expected by demonstrating that you will invest time and creative strategy in a design concept. Boundary pushing proves that you are a thinker and a doer, not a follow-the-leader-er." It needs to start with design history, take risks and stay open; in other words, read, research, explore, innovate and create.

Creative Anarchy: How to Break the Rules of Graphic Design for Creative Success
Author: Denise Bosler
Publisher: HOW Books
January 2015
ISBN: 978-1-4403-3332-3
240 pages
Paperback
Available also as an eBook



Middle East, China, and Korea is considered. The historical survey is concluded with a discussion of the emergence and impact of electric and electronic communication technologies. Last four chapters address the interaction of new communication technologies and human societies. Four generic alternative futures are examined.

The Layout Book

Author: Gavin Ambrose

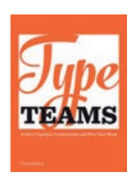
Publisher: Fairchild Books
2nd ed., January 2015
ISBN: 978-1472568236
192 pages, 200 images
Paperback
Also as an eBook

The Layout Book is a solid overview of layout design, offering a huge array of potential layout options.

Besides historical fundamentals and a systematic look at key theoretical principles of layout and their practical applications both in print or digital media, the second edition of this popular book primarily aimed at visual arts students includes interviews with practicing designers, as well as new exercises to aid readers in their own explorations.

Type Teams: The Principles Behind Perfect Type Face Combinations

Author: Tony Seddon



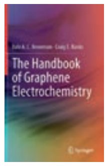
Publisher: HOW Books
February 2015
ISBN: 978-1440335211
224 pages
Hardcover

Tony Seddon, the author of Graphic Design for Non-designers, developed this typography book for typographers and graphic designers with the ambition to help with finding appropriate typeface combinations and incorporating several fonts into creative projects.

Type Teams guide provides 150 examples of typeface combinations, organized into 25 contrasting categories, ranging from Scholarly and Classical to Edgy and Vibrant.

The Handbook of Graphene Electrochemistry

Authors: Dale A. C. Brownson, Craig E. Banks



Publisher: Springer
2014
ISBN: 978-1447164272
201 pages, 126 images
Hardcover
Also as an eBook

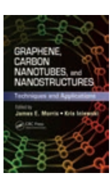
Graphene as the potentially thinnest electrode material has been widely reported to perform beneficially over existing electrode materials when used within energy production or storage devices and when utilised to fabricate electrochemical sensors.

After a brief history of graphene and outline of its fabrication and unique properties, this book gives a fundamental introduction into graphene electrochemistry, enabling the readers to effectively explain and interpret graphene literature, as well as to design and implement electrochemical experiments utilising graphene as an electrode material.

Presenting the electrochemistry background, the book is accessible to not only postgraduate researchers, academics and industrialists, but also undergraduate students.

Graphene, Carbon Nanotubes, and Nanostructures: Techniques and Applications

Editors: James E. Morris, Krzysztof Iniewski



Publisher: CRC Press
February 2013
ISBN: 978-1466560567
364 pages, 185 images
Hardcover
Also as an eBook

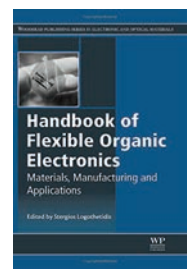
The book aimed at professionals, researchers and graduate students examines the evolution and emerging trends of nanofabrication as well as the most important underlying technologies, with an emphasis on graphene, carbon nanotubes, and nanowires. It gives both theoretical and experimental reviews on nano-structure device engineering. Among a wide range of topics, the protective layers on silver nanoparticles for inkjet printing are included.

Handbook of Flexible Organic Electronics: Materials, Manufacturing and Applications

This technical resource should be of interest to academics and researchers in physics, chemistry, biology, material science and engineering, as well as to R&D managers in industrial sectors, such as nanotechnology, electronics, lighting, telecommunications, information technology, automotive, biotechnology and advanced printing.

First chapters explain mechanics of curvature and strain in flexible organic electronic devices and introduces materials for their production – fullerene-based organic materials, hybrid and nano-composite materials and organic polymeric semiconductor materials. Next part is focused on technologies, including roll-to-roll printing and coating techniques for manufacturing large-area flexible organic electronic materials and integrated printing for 2D/3D flexible organic electronic components and devices. Other chapters describe e.g. in situ characterization, in-line monitoring and quality control. Final part looks at applications for flexible organic devices – smart integrated systems and circuits for automotive applications, chemical sensors, microfluidic devices, two terminal organic non-volatile memory devices, printed batteries and other power storage devices.

Handbook of Flexible Organic Electronics:
Materials, Manufacturing and Applications
Editor: Stergios Logothetidis
Publisher: Woodhead Publishing
1st ed., December 2014
ISBN: 978-1-78242-035-4
478 pages
Hardcover
Available also as an eBook

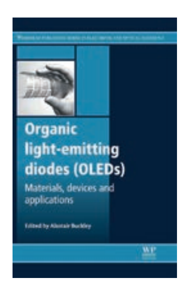


Organic Light-Emitting Diodes (OLEDs): Materials, Devices and Applications

This publication summarized key research on materials, engineering and the range of applications of organic light-emitting diodes. First part reviews conjugated polymers, transparent conducting thin films, iridium complexes and phosphorescent materials and their important properties. Second part discusses the operation and engineering of OLED devices, such as highly efficient pin-type OLEDs, amorphous organic semiconductors, nanostructuring techniques, light extraction, colour tuning, printing techniques, fluorenone defects and disruptive characteristics as well as durability issues. Third part explores the applications of OLEDs including displays, microdisplays and transparent OLEDs, sensors and large-area OLED lighting panels.

The aim of the book is to become a standard reference for engineers working in lighting, display technology and the consumer electronics sectors, as well as those researching OLEDs and graduate students in related fields.

Organic Light-Emitting Diodes (OLEDs):
Materials, Devices and Applications
Editor: Alastair Buckley
Publisher: Woodhead Publishing
1st ed., August 2013
ISBN: 978-0-85709-425-4
666 pages
Hardcover
Available also as an eBook



Bookshelf

Academic dissertations

Printed Dye Sensitized Solar Cells with Modified Electrodes

The object of this dissertation was the preparation of functional dye sensitized solar cells (DSSC) with printed photoanodes and catalytic layers of counter electrodes with various compositions.

First, standard DSSCs with screen printed TiO_2 photoanodes, ruthenium dye as a sensitizer, iodine electrolyte and a counter electrode with Pt catalytic layer were prepared. The amount of ethyl cellulose as a rheological agent of the TiO_2 screen printed dispersions has significantly influenced not only their viscosity and thixotropy, but also the thickness and roughness of the electrodes, the amount of absorbed dye and the efficiency of DSSC. All parameters have reached the optimum in the same range of ethyl cellulose concentration. The presence of the $TiCl_4$ photoanode blocking layer has increased the recombination resistance of the cells and consequently their voltage, photocurrent and efficiency from 2,5 to 4,2 %. Further, composite TiO_2/ZnO photoanodes were prepared from low temperature dispersions of nano oxides in n-butanol on ITO/PET foils. The effect of various compositions of photoanodes on photovoltaic characteristics of DSSC was evaluated and the best results were reached with the combination of various sizes of ZnO nanoparticles.

The final aim of the thesis was to substitute the standard Pt catalytic layer of counter electrode with conductive polymers PEDOT:PSS and polypyrrole (PPy) in combination with multiwall carbon nanotubes (MWCNT). PPy coated MWCNT dispersions were more efficient than dispersions of PPy/Ag with MWCNT and the presence of MWCNT has significantly increased adhesion and catalytic activity and lowered catalytic resistance. For the PEDOT:PSS dispersions, the impact of rheological agent on the electrical and electromechanical characteristics of layers and photovoltaic parameters of DSSC were evaluated. The 2,9 % efficiency that was reached is the highest for the screen-printed PEDOT:PSS counter electrodes without the addition of carbon nanomaterials, according to the available literature.

Doctoral thesis – Summary

Author:
Pavol Gemeiner

Speciality field:
Technology of Macromolecular Materials

Supervisor:
Milan Mikula

Defended:
19 August 2014 at STU / Faculty of Chemical and Food Technology Bratislava, Slovakia

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Study of Functional Systems on Base of Electrically Conducting Polymer Layers

This thesis deals with the application of conducting polymers by means of printing and coating. The inks on the base of three different groups of conducting polymers (polythiophene, polyaniline and polypyrrole) were prepared from the colloidal dispersions. First, the process of the conducting polymer synthesis was optimized in terms of the requirements on the each application technique and the dispersion properties. The main stress was put on the polyaniline based dispersion systems, prepared using different stabilizers, solvents and ratios between the conducting polymer and the stabilizer. As the stabilizers, polymers (poly(N-vinylpyrrolidone), poly(vinyl alcohol) and hydroxyethyl cellulose) as well as "small" molecule surfactant (sodium 1,4-bis(2-ethylhexoxy)-1,4-dioxobutane-2-sulfonate) were tested. As the solvents, water, mixture of water and isopropyl alcohol, xylene and chloroform were applied. Dispersions of poly(3,4-ethylenedioxythiophene) poly(styrenesulfonate) (PEDOT:PSS) were studied in a form of commercially available as well as specially synthesized material (with different PEDOT to PSS ratios and different concentrations). A short study was devoted to the

Doctoral thesis – Summary

Author:
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Technology of Macromolecular Materials

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preparation and application of polypyrrole silver based composites with two different stabilizers (poly(N-vinylpyrrolidone) and poly(vinyl alcohole)).

The prepared polyaniline and PEDOT:PSS dispersions were optimized with regards to the viscosity and surface tension and then applied by means of various printing (inkjet printing, screen printing and gravure printing) and coating (spin coating, bar coating and spray coating) techniques. Depending on the ink properties, deposition process and the set process parameters, the films of different thickness, roughness, conductivity, visible light transmission and morphology were received. The differences in the obtained film's properties and the influence of the modified parameters are discussed in detail. The conductivities ranged from 10^{-8} to 10^{2} S cm^{-1}, thickness and roughness varied from several tens of nm to units of µm, and several nm to hundreds of nm, respectively. Finally, the acquired knowledge about the conducting polymer material and the deposition process was used for the fabrication of functional electronic devices. The inkjet-printed and spray-coated polyaniline based sensor with the response to ammonia vapours exposure was demonstrated. The dye sensitised photovoltaic cells with screen-printed PEDOT:PSS based counter electrodes with the power conversion efficiency of up to 3 % were fabricated. The flexible thin film organic field effect transistor with inkjet-printed source/drain electrodes on the base of PEDOT:PSS was successfully prepared as well.

Doctoral thesis – Summary

Author:
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Speciality field:
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Metal Films for Printed Electronics: Ink-substrate Interactions and Sintering

The thesis aims to clarify how the ink-substrate interactions and sintering methodology affect the performance and reliability of inkjet-printed nanoparticle patterns on flexible substrates. This improves the selection, adaptation, design and manufacturing of suitable substrates for inkjet-printed high conductivity patterns, such as circuit boards or RFID antennas.

Paper substrates of various type and construction were characterized, and the characteristics were related to the performance of inkjet-printed metal patterns. Fast absorption of the ink carrier was beneficial for well-defined pattern geometry as well as high conductivity. On the other hand, surface roughness with topography variations of sufficiently large amplitude and frequency was detrimental to the pattern definition and conductivity. Porosity was another important factor, where the characteristic pore size was much more important than the total pore volume. Apparent surface energy was important for non-absorbing substrates, but of limited importance for coatings with a high absorption rate. Applying thin polymer-based coatings on flexible non-porous films to provide a mechanism for ink solvent removal improved the pattern definition significantly. Inkjet-printing of a ZnO dispersion on uncoated paper provided a thin spot-coating, allowing to form conductive silver nanoparticle films.

The resulting performance of printed metal patterns was highly dependent on a well adapted sintering methodology. Several sintering methods were examined in this thesis, including conventional oven sintering, electrical sintering, microwave sintering, chemical sintering and intense pulsed light sintering. Specially designed coated papers with modified chemical and physical properties were utilized for chemical low-temperature sintering of silver nanoparticle inks. For intense pulsed light sintering and material conversion of patterns, custom equipment was designed and built. Using the equipment, inkjet-printed copper oxide patterns were processed into highly conducting copper patterns. Custom-designed papers with mesoporous coatings and porous precoatings improved the reliability and performance of the reduction and sintering process.

Events

WAN-IFRA Events

10th WAN-IFRA Middle East Conference

Dubai, UAE
15–16 April 2015

This Conference of World Association of Newspapers and News Publishers aims at revealing the shape which the future of publishing is taking. After the summary of World Press Trends by Vincent Peyrègne, WAN-IFRA Chief Executive Officer, the opening keynote of Kerry Northrup is going to Imagine it's 2020. The future of news is expected to be something completely new – the rise of engagement, activity-tracking wearables making situationally reactive content the norm, publishers as news experience producers, microvideo everywhere, everything social, media not as a product but as a service; but also the end of advertising and disappearance of the websites as are known today. The Internet of Things and digital in general are driving consumers shift towards personalized brand experiences.

Innovations in newsrooms and in print will be presented, including a case study how two Sri Lankan Newspapers used innovations as a differentiation strategy to create a distinct image in the minds of readers. The goal of the lessons from the magazine industry is to answer the questions like why do magazines continue to thrive in a digital age and why are digital companies moving to print. Finally, Manfred Werfel, WAN-IFRA Deputy CEO, will moderate the discussion on Print versus Digital – looking at how the printed newspaper has continued to develop in recent years and what can still be expected from it, and seeking the answer to the question: Is print on its way out, or can it remain an essential part of a multimedia world?

Digital Media Europe 2015

London, UK
20–22 April 2015

Five themes will define DME2015: Attract and build a business around a younger demographic (Media for Millennials); Keep premium pricing and stay safe from market fraud (Programmatic Advertising); Make data actionable (Data Strategy); The cross-media tracking dilemma (Media Measurement); and Strategies to create ad friendly quality content (Video).

67th World News Media Congress | 22nd World Editors Forum 25th World Advertising Forum

Washington, D.C., USA
1–3 June 2015

These summit meetings of the world's press are organised in cooperation with the Newspaper Association of America. Global executives from media industry and experts from other industries will meet in June to share their strategies, insights and advice on perspectives and media trends around the world.

PIA Conferences

2015 Continuous Improvement Conference

Minneapolis, MN, USA
12–15 April 2015

This conference presented by Printing Industries of America, in partnership with Flexographic Technical Association (FTA) and Specialty Graphic Imaging Association (SGIA), is focused on concepts of Lean Manufacturing and other management and quality systems to reduce costs, lower waste, and increase profit margins. Attendees represent firms spanning the whole industry, producing packaging, direct mail, books, labels, signs and displays, publications, and specialty work. Sessions on Leadership and Culture, and Process and Tools on Advanced or Fundamental level can be chosen.

2015 Printing Industries Financial Executives (PIFE) Conference

Minneapolis, Minnesota, USA
12–15 April 2015

PIFE Conference program is focused on new ways to save money, explore potential investments to grow business, and gain insight into the current marketplace.

2015 BIA Annual Conference

Minneapolis, Minnesota, USA
18–20 May 2015

The Binding Industries Association (BIA) represents trade binderies, graphic finishers, custom loose-leaf manufacturers, information packagers, and suppliers to these industries. This year's conference is co-located with the Print Leadership Summit. The postpress community can meet customers and peers as well as come together with printers. Panel discussion on making the company more valuable to the printer or the talk on growing importance of finishing and special effects printing are included in the program.

CIP4 InterOp Meetings

Tokyo, Japan
13–17 April 2015

Worldwide organized InterOp meetings allow CIP4 members to meet face to face and jointly work on improvement of their products. The first phase is dedicated to the actual technical testing, where anyone can bring their JDF enabled product and test its interoperability with other matching products. The second phase consists of meetings of the technical work groups. Topics of discussion range from new features over interpretation of individual attributes to philosophical debates at times.

After the last InterOp meeting, which took place in Barcelona, the upcoming one will be hosted by Heidelberg in Tokyo. Among the topics in focus, coordinate systems, digital finishing and Pipe ICS (Interoperability Conformance Specification) can be found together with XJDF (JDF 2.0), which is a simplified version of JDF. It is designed to be a pure information interchange interface, leading to a significant reduction of complexity compared with the original JDF design. This should bring faster, simpler and more robust integration of devices and applications in the graphic arts industry. The next InterOp meeting is scheduled on 12–16 October 2015 in Paris.

INFO*FLEX 2015: 33rd Annual Exhibition

Nashville, Tennessee, USA
4–5 May 2015

INFO*FLEX, organized by Flexographic Technical Association, is the traditional event for package printing and converting professionals with still increasing show floor and attendance. The most of attendees come from segments of flexible packaging and tags & labels, accompanied by representatives of folding carton, corrugated board and specialty printing segments.

The London Book Fair

London, UK
14–16 April 2015

The London Book Fair (LBF), taking place at Olympia this year, is not only the global marketplace for rights negotiation and the sale and distribution of content across all media channels, but also the opportunity to visit related conferences and 250+ free-to-attend seminars covering a wide range of topics.

At the first day of the London Book & Screen Week on 13 April 2015, the program starts with the Publishing for Digital Minds Conference (pDMC). This conference will welcome leaders in fields as diverse as social content and educational publishing along with pioneers of new business models. The sessions on how the world of books can work with and alongside social content producers, independent analysis of Amazon, effective content strategy, crowdsourcing and relevance of a pay-as-you-go business model for books are planned. The 'Lessons to be learned' panel will focus on the huge opportunities for publishers and content professionals in the education market. The interactive session will give delegates the opportunity to question publishing leaders directly. In the afternoon, the Introduction to Rights Conference also will take place, covering topics on selling rights or guidelines for a rights deal and contract checklist.

On the final day of LBF 2015, What Works? Education Conference and CMC Rights Exchange are organized. The conference is focused on how best to deliver different kinds of information in a classroom for maximum effect, and how to maximize the resources available. The latter one is the UK's market event for children's publishers, authors' agents, TV, interactive, film, games and app producers.

Printed Electronics Europe 2015

Berlin, Germany
28–29 April 2015

This event which is organized by IdTechEx since 2004 is dedicated to the commercialization of printed, organic and flexible electronics, and is covering organic, inorganic, thin film and flexible nanotechnologies. The aim is to focus on end-user needs and sector requirements, clarify the latest technology and product developments and their roadmaps, clear market insight and sector appraisal.

Co-located tradeshow, masterclasses and two-day conferences will explore state-of-the-art in 3D printing, extracting energy from heat, light, motion, biology, RF and other means to power small devices to vehicles, advances made and envisaged for land, water and air vehicles, all promising applications of graphene, Internet of Things business models, case studies, actions, profitability and missing gaps, and applications as well as commercialization progress of wearable technologies.

Conference on Hybrid and Organic Photovoltaics 2015

Rome, Italy
10–13 May 2015

The generous progress of perovskite solar cells will be a key focus of the International Conference on Hybrid and Organic Photovoltaics (HOPV) in its 7th year. Other topics covered by the conference include dye-sensitized and quantum dot solar cells, bulk heterojunction solar cells, as well as small molecule organic solar cells, and also solar fuel production catalysts and devices, hybrid organic-inorganic and nanostructured devices, and artificial photosynthesis. With Michael Grätzel, Martin Green and Daniel Nocera as the keynote speakers, 15+ invited speakers and tens of contributed oral talks accompanied by numerous poster presentations, the program of a full three days conference makes it a major event presenting the advances in the field.

On the next day, 14 May 2015, the workshop on Design, fabrication and scaling-up of mesoscopic solar cells: from dye sensitizers to perovskites is organized in Rome. Besides the design and fabrication, the characterization of mesoscopic solar cells will be on the program.

FESPA 2015

Cologne, Germany
18–22 May 2015

The global exhibition for wide format digital, screen and textile print with more than 700 exhibitors demonstrating technology, applications and consumables, FESPA 2015 explores growing sectors like digital textile and fabric print, as well as DTG (direct to garment) technology. As the new market opportunities, 3D printing, interior decoration, non-printed and digital signage are presented. Visitors can attend a large number of both introductory and advanced seminars and workshops. The call is now open for FESPA's 2015 Awards with the prize-giving ceremony at FESPA's Gala Dinner on 19th May 2015, including The Young Star award for an employee or student in a print related discipline between 16 and 25 (a prize of €500 and a 6 week internship with category sponsor MIMAKI).

European Sign Expo 2015

The annual European Sign Expo (co-located at FESPA 2015) for sign-makers and visual communication practitioners presents innovation in both conventional and digital signage. Signage producers can see the latest solutions in channel lettering, signage systems, illuminated displays (including neon and LED), etching and engraving, as well as digital signage.

Printeriors 2015

Another FESPA 2015 co-located event invites the interiors and architectural design community to connect with international print agencies and suppliers offering an insight into the versatility and power of print for interior design and decoration. Creative room sets for Retail, Residential, Corporate and Hospitality scenarios will be presented, including print techniques for carpet printing, wallpaper coverings, fabric print, to glass branding and soft furnishing. The dedicated one day conference held on 21 May 2015 will give an overview of the printed interiors market, covering application, techniques, case studies and ideas.

From 3 to 6 May, the co-located Forum 2015 will offer insights into process control, packaging trends like brand protection solutions and interactive packaging, industry standards, workforce management and more. Flexographic Quality Consortium will present its many ongoing projects and the findings of industry initiatives of Near Neutral Calibration for Corrugated and High Resolution Printing. The Research that Resonates session will also showcase funded student research projects in printed electronics and plate recycling technology.

Fogra Symposium:
Digital Printing Meets Offset

Munich, Germany
12–13 May 2015
Only in German

The two-day symposium is aimed at those looking for up-to-date expert information on toner-based digital, inkjet and small offset printing, being of great importance for efficient production of small print runs.

Digital Print for Packaging US

Tampa, Florida, USA
1–2 June 2015

This Smithers Pira's conference offers insight into the implementation of digital print for packaging. This year's program will look at various digital technologies, applications and sectors. The current market needs will be analysed, including the assistance required from the industry by the brands already engaged in digital print for packaging, as well as those not yet using the technology.

The state of the digital print industry will be explored, breaking the industry down into sections such as corrugated and folding carton to gain a clear understanding of the key developments in each area and how digital print requirements vary or express similarities. Case studies will present digital print within applications such as food and beverages, pharmaceuticals and more. The future projection of the industry will include presentation on retail exploration of digital print and possible effects on the supply chain, digital print for packaging recognition and predictions for the industry in 2020 in terms of the future of analogue and digital printing methods. The conference will be concluded by the question and answer session with leading technology providers (like Hewlett Packard) and their customers.

Dscoop EMEA Conference

Dublin, Ireland
3–5 June 2015

The 4th Dscoop (Digital Solutions Cooperative) EMEA conference will feature 50 educational seminars presented by leading experts and digital print providers from across EMEA. It is an opportunity for digital printers to come together and learn about the industry trends, new technology and applications, and share best practice. They will have access to the HP and Dscoop Partner products and services, including nine HP Indigo presses, as well as the latest Latex, DesignJet and PageWide Technology. The sales and marketing tool kits, created exclusively for Dscoop members, will be introduced.

plast pack: 1st International Trade Fair for Packaging and Printing Machinery and Material

Casablanca, Morocco
3–6 June 2015

The 1st plast pack completes the 6th plast expo, the event held every other year in Morocco, the fifth largest importer of packaging, printing and paper technology in Africa.

CIE 2015: 28th Session

Manchester, UK
28 June to 4 July 2015

In the International Year of Light 2015, the International Commission on Illumination (CIE), which has recently celebrated its 100th anniversary, will hold its 28th Session – a scientific meeting supporting cooperation, discussion and dissemination.

NANOTEXNOLOGY 2015

Thessaloniki, Greece
4–11 July 2015

NANOTEXNOLOGY 2015
International Conferences & Exhibition on Nanotechnologies & Organic Electronics
4-11 July 2015, Thessaloniki, Greece

NANOTEXNOLOGY consists of several events on Nanotechnologies & Organic Electronics. The International Summer Schools in the 9th edition can be attended during the whole time span and are divided in three complementary schools – Nanosciences & Nanotechnologies, Organic Electronics, and Nanomedicine, with plenary and parallel sessions in the program. The 5th NANOTEXNOLOGY Expo is open from 6 to 10 July.

The 12th International Conference on Nanosciences & Nanotechnologies takes place on 7–10 July and is focused on photovoltaics, polymer nanotechnologies, bioelectronics, graphene and related materials, nanomedicine related issues and nanoconstruction. Moreover, commercialization and funding will be covered. The 8th International Symposium on Flexible Organic Electronics is organized on 6–9 July. The goal is to share the knowledge needed to solve problems related to nanomaterials (e.g. morphology, phase separation, interfaces, charge generation & transport, upscalability to large area processes) and to devices. Further, the progress in the theoretical modelling & computational methods will be presented. At the same time, the importance of understanding of the basic mechanisms & phenomena and establishing the structure-property relationships to allow the market implementation of organic electronics devices is also recognized.

47th IC Conference

San Luis Obispo, California, USA
5–10 July 2015

The 47th Conference of the International Circle of Educational Institutes for Graphic Arts, Technology and Management (IC) is hosted by California Polytechnic State University (Cal Poly) and organized with the 93rd Annual Conference for the Graphic Communication Education Association (GCEA). For the first time, these two organizations have joined to rally around scholarly and applied research in the graphic arts, technology, education and management fields. Additionally, PrintED Consortium teachers will hold a one-day conference and then partake in the joint IC/GCEA festivities. All this will kick-off the 70th anniversary celebrations of the Graphic Communication program at Cal Poly.

The theme of the conference is The Release of Graphic Communication 3.5. The objective is to address questions related to emerging fields in Graphic Communication and Media Technology. Topics will explore the latest developments in design and technology used for mobile, online, and print media, as well as the educational consequences of these developments. Paper and poster presentations will be accompanied by workshops, demonstrations, and applied seminars facilitated in the Graphic Communication Department lab space.

Call for papers

The Journal of Print and Media Technology Research is a peer-reviewed periodical, published quarterly by iarigai, the International Association of Research Organizations for the Information, Media and Graphic Arts Industries.

JPMTR is listed in Index Copernicus, PiraBase and PaperBase (by Smithers Pira) and NSD – Norwegian Register of Scientific Journals, Series and Publishers Pira.

Authors are invited to prepare and submit complete, previously unpublished and original works, which are not under review in any other journals and/or conferences.

The journal will consider for publication papers on fundamental and applied aspects of at least, but not limited to, the following topics:

- Printing technology and related processes

  Conventional and special printing; Packaging; Fuel cells and other printed functionality; Printing on biomaterials; Textile and fabric printing; Printed decorations; Materials science; Process control

- Premedia technology and processes

  Color reproduction and color management; Image and reproduction quality; Image carriers (physical and virtual); Workflow and management

- Emerging media and future trends

  Media industry developments; Developing media communications value systems; Online and mobile media development; Cross-media publishing

- Social impact

  Environmental issues and sustainability; Consumer perception and media use; Social trends and their impact on media

Submissions for the journal are accepted at any time. If meeting the general criteria and ethic standards of scientific publishing, they will be rapidly forwarded to peer-review by experts of high scientific competence, carefully evaluated, selected and edited. Once accepted and edited, the papers will be printed and published as soon as possible.

There is no entry or publishing fee for authors. Authors of accepted contributions will be asked to sign a copyright transfer agreement.

Authors are asked to strictly follow the guidelines for preparation of a paper (see the abbreviated version on inside back cover of the journal). Complete guidelines can be downloaded from:

http://www.iarigai.org/publications/

Papers not complying with the guidelines will be returned to authors for revision.

Submissions and queries should be directed to:

journal@iarigai.org

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/ethicguidelines.

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Submitting the contribution to JPMTR, the author(s) confirm that it has not been published previously, that it is not under consideration for publication elsewhere and - once accepted and published - it will not be published under the same title and in the same form, in English or in any other language. The published paper may, however, be republished as part of an academic thesis to be defended by the author. The publisher retains the right to publish the printed paper online in the electronic form and to distribute and market the Journal (including the respective paper) without any limitations.

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 attained, relationships), and your interpretation and main consequences of your findings (discussion, conclusions). The abstract must reflect the content of the article, including all the 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 possible 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.

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1-2015

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