Research on paper-ink-process interactions in electrophotographic and ink jet printing

Pirkko Oittinen, Hussain AL-Rubaiey, Katja Sipi and Katri Vikman,
Helsinki University of Technology,
Laboratory of Media Technology,
Espoo, Finland

Abstract

The research is motivated by needs of quality improvement in electrophotography and ink jet. From a materials perspective, understanding of the interactive phenomena between paper, inks and the process – the printing process or the end use processes – is a means towards this end. The overall goal of the research is to gain understanding of interactive phenomena by experimentation, characterization of print structure, measurement of print properties and result modeling. This paper focuses on the methodology in interaction and print structure research.

In electrophotographic printing, paper, toner and the printing process interact mainly in the toner transfer and fusing steps. In ink jet printing, the corresponding process steps are drop impact and drying. In the use processes, environmental interactions cause aging and changes in print structure.

The paper discusses and evaluates methods used in investigations of three-component interactions in electrophotographic printing and ink jet aging, and the resulting print structure. The former include electrical measurements of toner transfer and experimentation of contact and non-contact fusing in electrophotography. In both electrophotography and ink jet, spectroscopic methods, (FTIR and Raman techniques), are used for characterization of print structure.

Introduction

Runnability and printability are the classical terms which depict the usability of paper in printing. During its life cycle, printed paper is also subjected to consumer and post-consumer end use processes. Terms archievability and deinkability give expression to some aspects of their interactions.

In essence, runnability is the outcome of paper and printing process interactions, and printability of ink (or toner; called collectively ink), and paper interactions. In other words, the terms refer to two-component interactions. In the case of printability, neglecting the influences of the process, the assumption is tacitly made that the interactive phenomena and their relative significance remains essentially the same in different process conditions. Based on this, the further assumption is made that also the performance relations of different paper or ink samples remain the same. The assumptions of course need not be true, because the interactive phenomena in different process conditions may not be the same or their relative importance may change.

Several approaches to accommodate the process in the research framework of interactions can be taken. They include the following:

1. experimentation by variation of process parameters,
2. monitoring process phenomena in real time and
3. monitoring the development of print structure or print properties in the process.

In the first two cases, print structure and print properties are measured afterwards. Print structure here means the physical and chemical structure, in other words the x,y,z-distribution of ink and its components in relation to the paper structure on micro and submicro scales.

Methods in Interaction Studies

Toner transfer

The micro scale evenness of toner transfer to paper in terms of x, y and z-coordinates has turned out to be a critical print quality factor in four-color electrophotography. It is argued that improvement of understanding of unevenness requires more thorough knowledge of the transfer phenomena on the macro scale.

The research approach taken combines the first and second categories in the above list. With reference to the first, a commercial four-color multi-pass desktop laser printer with a transfer drum configuration has been equipped with adjustment of transfer voltage. The relations of transferred toner amount and voltage give support to deductions of transfer phenomena and support quantitative modeling.

Second, to monitor the transfer process, the printer has been equipped with measurement of transfer current. Fig. 1 illustrates the configuration. It allows recording of the flow of current in the transfer zone as the photoconductor revolves. For each four-color print four or five revolutions are made. The first of five revolutions is for registering the paper on the transfer drum.

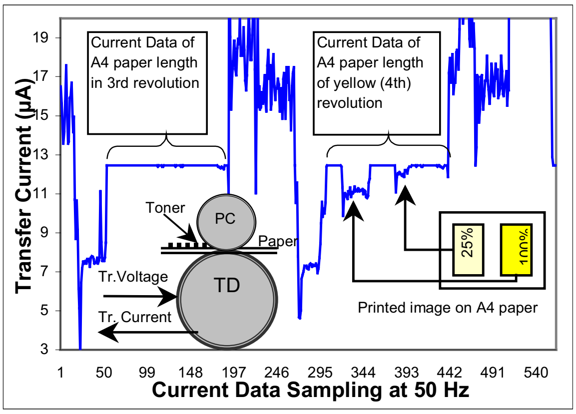

Figure 1. Measurement of transfer current.

Sampling at 50 Hz.

Measured current responds sensitively to any change in the materials, such as the bulk and electrical properties of the paper, the q/m of the toner, and also relative humidity. The measurement has turned out to be highly reproducible. Fig. 2 shows how the moisture content of paper influences the transfer current during toner transfer.

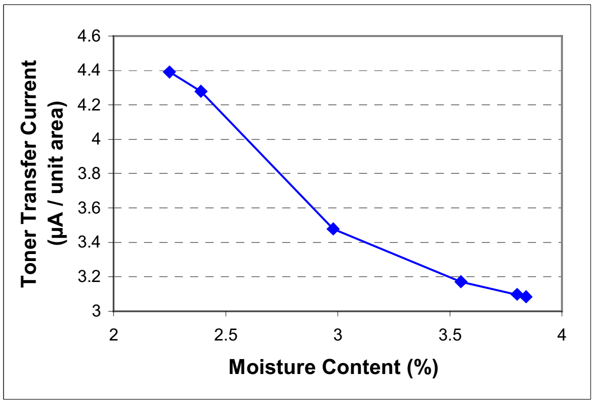

Figure 2. Influence of moisture content of paper on toner transfer current.

On-going research explores the mechanisms accounting for transfer current and amount of transferred toner[1].

Efforts have also been made to measure surface potential on paper after transfer. The experience is that the measuring point should be very close to the transfer zone and the sensitivity of measurement considerable for meaningful data.

Fusing

The challenges of toner fusing as a research topic, arise from needs for energetically more efficient fusing methods and needs for better fusing quality. The latter is true especially with coated papers.

The approach so far in the study has fallen in the first category named above. Some existing nip fusing systems have been modified or equipped with adjustments for variation of process parameters. For non-contact fusing by infrared and NIR flash radiation, new installations have been constructed. Table 1 gives a summary of the facilities currently available.

Table 1. Facilities for fusing experimentation and their variables.

Fusing method	Adjustable variables
Hot nip fuser	Dwell time Temperature of both rollers
Hot long nip fuser	Pressure Roller hardness
IR installation	Speed of paper Temperature of ceramic radiators 1 or 2 sided fusing
Flash fusing installation	Energy (pulse width, intensity)

Completed research has focused on fusing with a combination of two methods such as nip and IR fusing[2]. Combinations are of interest from both energy and print quality viewpoints. Fig. 3 illustrates toner adhesion in single and double fusing experiments as function of print density. In general, the second step causes changes in most quality factors as well as their small-scale variation, but the first step is decisive.

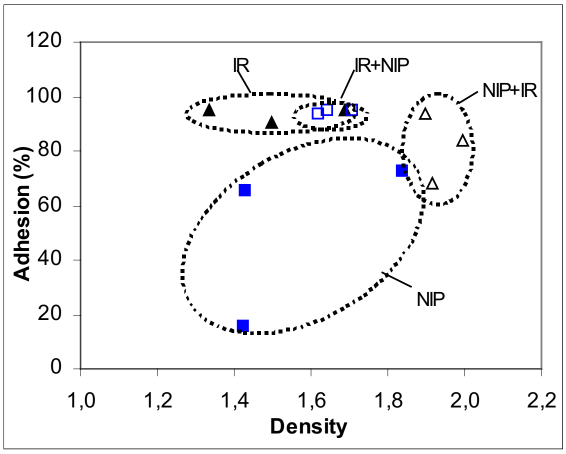

Figure 3. Example of fusing experiments with different combinations of nip and IR fusing.

Current research deals with print structure and fusing quality achieved in different fusing conditions[3]. Moreover, the feasibility of long nip fusing is investigated from a quality viewpoint.

Aging

In many of the present ink jet applications, the prints are expected to retain their optical properties for many years, even when exposed to light, moisture or mechanical stress. The role of interactions between ink and paper in determining fastness properties of an ink jet print is still unclear. For this reason achievement of excellent fastness properties with various inks and media in all operating situations is complicated.

Aging studies are accomplished by monitoring changes in print structure in the aging process. The approach is consistent with the third option in the above list. In the experiments, monitoring, however, takes place off-line. This is facilitated by the slowness of aging phenomena; the process can be interrupted for print structure analysis. Aging of printed samples is effected by exposure to artificial sunlight for different lengths of time (6-100 hours) with a Suntest CPS+ xenon arc lamp. The test chamber settings are 615 W/m^2 (150 klux) for irradiance and 40°C for black standard temperature. Constant irradiance is used because conditions in this respect are fairly stable also in home and office environments.

The test set-up does not allow control of the humidity and temperature of the test chamber. This is likely to result in some uncontrolled variation in the data.

Changes in print structure caused by aging are being investigated by spectroscopic methods[4]. Changes over time in print properties are measured as colour differences, and water and mechanical fastness. Fig. 4 shows an example of color change over time for a yellow print. The three color coordinates, L*, a* and b*, are changed distinctly differently. Spectroscopic print structure analysis is used to find how the changes can be traced to changes in molecular structure[5].

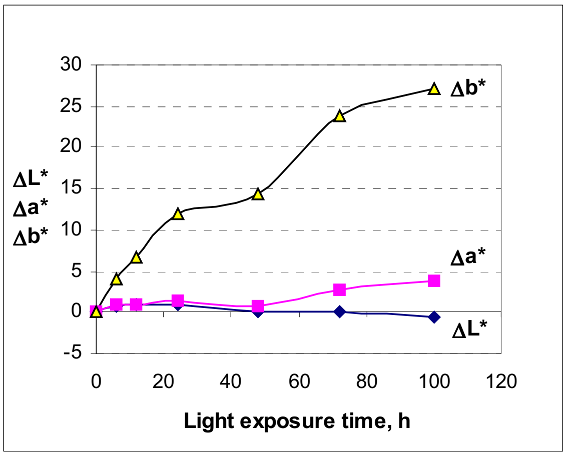

Figure 4. Example of color change with exposure time for a yellow ink jet print.

Print Structure Analysis

Traditional print quality measurement methods do not yield enough information for deduction of interfacial mechanisms between ink or toner, and paper, hence other methods are needed. Many analytical methods, such as microscopic methods combined with thin-cuts of paper, and chromatographic methods, have been used in in paper and printing related research. Unlike many other analytical techniques, vibrational spectroscopy, or IR and Raman spectroscopy, enables the studies of prints "as is", and thus provides information on the actual print structure. Table 2 gives a sum-up of techniques currently used in spectroscopic print structure analysis.

Table 2. Methods in spectroscopic print structure analysis.

Property	IR	Raman
Excitation source	Polychromatic light (IR-radiation)	Monochromatic light (laser)
Basic phenomenon	Absorption of IR-radiation	Inelastic light scattering
Molecular activity	Change in dipole moment	Change in polarizability
Active vibrational modes	Asymmetric polar bonds (i.e. O-H, C=O)	Symmetric non-polar or slightly polar bonds (i.e. N=N, C=C)
x,y-direction mode	Micro-ATR, ATR Rapid-scan PAS DTGS	Microscope
z-direction mode	Step-scan PAS	Confocal measurement

Infrared and Raman spectroscopy are both based on molecular vibrations, but they are complementary methods, due to the different transfer mechanisms of energy from photons to exposed molecules[6]. Raman spectroscopy is applicable to ink/paper interaction studies of ink jet prints, due to its sensitivity to colorants.

Systematic testing of the different FTIR-methods (cf. Table 1) with ink jet samples indicated[5] that they are applicable to characterization of plain ink and unprinted paper.

Interaction related differences between printed samples could not, however, be discerned. This was due to problems of finding an IR technique with sufficient and controlled beam penetration into the sample. In the ATR technique using Ge crystal, the penetration depth was too small, whereas in the step-scan PAS, penetration was excessive despite the use of high modulation frequencies. The use of another crystal material may solve this problem. In the case of electrophotographic print studies, FTIR spectroscopic methods proved to be applicable to studies of toner interactions.

As for the Raman method, especially the confocal technique holds promise. It allows sensitive depth profiling of ink jet colorants, toner pigments and print substrate. The principle of a newly developed technique[7] is illustrated in Fig. 5.

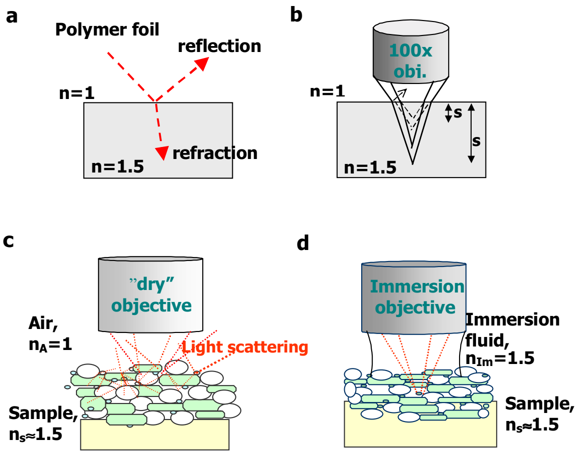

Figure 5. Light behavior in depth profiling[7].

As laser light impinges on a sample, a difference in the refractive indices causes light reflection and refraction at the optical boundary (a). Using a travelling objective the beam can be focused at different depths. In the basic mode, sample aberration, however, decreases depth resolution and causes variation in the sampling depth (b). Also light scattering diminishes the penetration depth and causes losses in spatial resolution (c). An immersion objective and suitable immersion oil (d) radically improve the depth profiling when light scattering samples, such as prints, are measured[7].

Discussion

In experimental research its achievements are closely linked to the methods. Their assessment and evaluation of developments needs is thus very important.

Transfer current monitoring provides a lot of data of the four-color transfer situation. The data are clearly meaningful. On the wish list for method development is implementation of monitoring in other transfer configurations than transfer drum, such as the intermediate belt configuration. Adjustment of process parameters in other configurations would also be desirable.

The situation in fusing is somewhat different. The current facilities cover a wide range of fusing configurations and allow parameter adjustments. What is lacking is means for monitoring fusing phenomena in the process. Equipment for monitoring temperature distributions in the toner, the toner-paper interface and in the paper, as unfused print passes through a fuser, would be of much interest.

Aging experiments are very time consuming. This limits the number of variables which is practical. Some versatility in the adjustments could yet be beneficial.

None of the set-ups currently used allows monitoring of the development print structure in real time. The needs, in the case of toner transfer and fusing are, however, minor. As mentioned above, aging can be interrupted and spectroscopic print analysis made off-line.

Fluorescence limits the use of given colors in Raman measurements with excitation in the visible band. This is a weak point because it limits the use of different colored inks and toners. The use of UV light in Raman measurement is believed to help overcome the problem and is being considered.

Conclusion

The topic of the paper, paper-ink-process interactions was discussed from the viewpoint of research approaches and methods. Especially the question of extending the traditional paper-ink approach to include the process – toner transfer, fusing or aging – was addressed.

Available set-ups support adjustment of process parameters, process monitoring and print structure analysis in a manner that is different in the three areas of the study. Also the needs are different. Despite some shortcomings the methods meet current needs.

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Biography

Dr. Pirkko Oittinen is Professor of Media Technology at Helsinki University of Technology, Mr. Hussain AL-Rubaiey is M.Sc. student and Ms. Katja Sipi and Ms. Katri Vikman Ph.D. students. Their joint research interest is digital printing. Mr. AL-Rubaiey works on toner transfer and fusing, Ms. Sipi on fusing and spectroscopic analysis and Ms. Vikman on aging and spectroscopic analysis of ink jet prints.