MEASUREMENT OF PRINTING INK PENETRATION IN UNCOATED PAPERS AND ITS INFLUENCE ON PRINT QUALITY

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ABSTRACT
The open surface of uncoated papers promotes printing ink penetration which causes loss of print density and - if the penetration is inhomogeneous - print mottle. Two methods for the measurement of printing ink penetration and variability are introduced. Both methods are based on cutting the printed paper sample and subsequent evaluation of the penetration depth of the printing ink in the paper cross section using digital image analysis.

Experimental evaluation of 8 rotogravure printed commercial SC-papers showed unexpectedly no correlation between ink penetration depth and print quality of full tone areas. However it was found that the penetration volume and the variation of the penetration depth have a significant influence on the colour density and the homogeneity of the print image.

INTRODUCTION

In rotogravure printing intense and inhomogeneous ink penetration affects the print quality negatively, especially for uncoated paper grades, like for example SC-paper. SC-paper has a very open surface and a large-pored capillary system, which – in combination with the applied low viscosity printing inks - promotes intense ink penetration [1]. The penetration of ink into the paper and the resulting change of the ink layer thickness on the paper surface reduce the optical efficiency of the print which causes loss of print density, print gloss diminution and, if the penetration is inhomogeneous, promotes print mottle. To gain a better insight into the entire effect of ink penetration it is thus necessary to measure its variation.

There are several methods to determine ink penetration in paper cross sections, which differ in sample preparation, image acquisition, sample size and resolution.

The most common method is based on microtomy. The sample is embedded in resin, thin cross sectional slices are cut on the microtome and these slices are imaged under a transmitted light microscope [2] [3]. If the ink has been labelled with an adequate fluorochrome also fluorescence microscopy can be applied [4]. The penetration depth and the distribution of the printing ink are subsequently measured by image analysis. Care must be taken with the selection of the proper embedding resin in order to avoid disturbing reactions between the printing ink and the resin. Dissolving of the ink may occur which makes analysis of the penetration depth impossible.

Another approach is the analysis of ink penetration by Scanning Electron Microscopy (SEM). In order to study the ink penetration of embedded paper cross sections in SEM backscatter images, a good contrast between fibres and ink pigments is required. For image contrast enhancement only a special, clay containing ink is used for printing which makes this method unsuitable for filled papers [5]. Cryo-SEM requires a high contrast liquid instead of conventional printing ink to allow differentiation from fibres. The practical application for print analysis is limited [6].

With Secondary Ion Mass Spectroscopy (SIMS) images of the printed paper cross section are acquired at a high resolution of 200-300 nm. The main disadvantage of this method is the dissolving of the printing ink due to reactions with the embedding resin [7]. A Focused Ion Beam (FIB) instrument can be applied for sample sectioning and recording the paper cross section directly with high resolution. Another application for the FIB-technique is the sample preparation for TEM-images where a thin lamella of the sample is cut out and the ink penetration is determined under the TEM [7]. Limitations of these methods are the small sample area and the therefore statistically insignificant results.

In a Confocal Laser Scanning Microscope (CLSM) the fluorescence emitted from fluorescent dyes, which are blended with regular dyes, is detected. A three-dimensional ink distribution can be obtained by optical slicing of the printed sample. The 3D-dataset is then constructed from several separately recorded xy-planes. The constraints of this method are the need of fluorescence dyes and the small sample size. Furthermore an impregnation of the sample is required which could interact negatively with the printing ink [8].

In all of the above introduced methods the paper sample is destroyed during the testing procedure. A non-destructive method is the estimation of the penetration depth from spectral reflectance on the basis of the Kubelka-Munk theory. Under the assumption that the ink is distributed homogeneously with constant intensity in the paper structure an average value for the penetration depth is obtained without information on the ink distribution [2].

Following the results obtained with the previously described methods are summarized. Analysis of cross sections of rotogravure printed SC-papers showed a correlation between high variation of the penetrated printing ink and poor print quality which was expressed as print density, print gloss and spreading of halftone dots [9]. The comparison of printability and penetration showed a reduction of the print density with increasing intensity of penetration. The influence of the penetration increases with rising scattering coefficient (i.e. porosity) [10]. Investigations of the influence of fillers, internal sizing and applied ink volume on the penetration of ink-jet inks in uncoated paper showed a strong correlation between the distribution of the sizing agent and the homogeneity of the penetration and between the ink volume and the penetration depth. The presence of filler had minor influence on the ink penetration [2].

THE SCALPEL CUTTING METHOD

As described in the introduction there are several methods for measuring ink penetration in paper substrates. The disadvantages of these methods are the small, statistically not representative sample size and in some cases the way of sample preparation. To avoid dissolving of the printing ink in the resin a method is preferred where no embedding is needed. One approach is the preparation of paper cross sections with a surgical blade and the examination under an incident light microscope with subsequent image analysis which is used for analysis of starch penetration. Due to the small sample size of < 1 mm a minimum of 16 cross-sectional images has to be examined to obtain representative results [11].

At the Institute for Paper, Pulp and Fiber Technology a similar method was developed to determine the penetration depth of the printing ink into the paper. The Scalpel Cutting Method [12] [13] provides a technique to measure and evaluate the ink penetration depth in paper cross sections of printed full tone areas. Best results are achieved for print substrates (e.g. SC paper) and print processes (e.g. rotogravure or ink-jet), where intense ink penetration occurs.

The first step of our method is to apply a plastic film to protect the printing ink layer against deformation during the cutting procedure. Secondly a manual cut through the printed paper is performed using a surgery scalpel. The cut sample is then mounted and positioned under a light optical microscope. The cutting edge is scanned under a light optical microscope at 100-times magnification and subsequent single images are acquired at several positions. The images are then stitched together to one composite image of the paper cross section. Finally the penetration depth is detected and measured along measuring lines placed at a 5 µm distance using image analysis (Fig. 1). With this method samples up to a cutting length of 20 cm can be analyzed, thus obtaining 40.000 measured values of penetration depth.

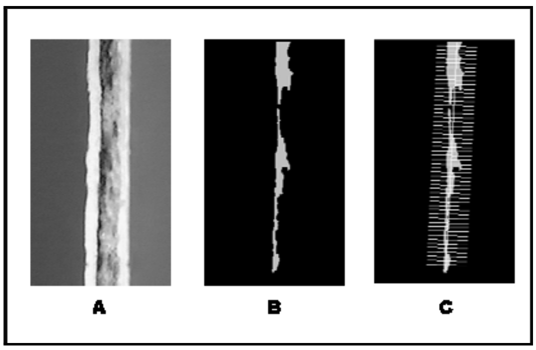

Fig. 1: (A) Paper cross section, (B) Detection of penetrated ink, (C) Measurement of penetration depth.

The advantage of the Scalpel Cutting Method is that it provides a simple and fast measurement with representative sample size for good statistical significance. Furthermore it needs no embedding in resin. The main disadvantage is the influence of the operator on the cutting procedure.

MEASUREMENT OF PENETRATION DEPTH USING MICROTOMY

A new method to measure ink penetration in paper cross sections of printed full tone areas was developed using a rotary microtome to ensure constant conditions during the testing procedure. Compared to the scalpel cutting method the cutting speed, the slice thickness and the compression of the sample can be regulated to minimize the influence of the operator on the test result. In contrary to conventional microtomy the printed paper is not embedded in resin for sample preparation but is mounted on the microtome by clamping the paper between two plastic foils in a sandwich construction (Fig. 2). From this package several thin slices are cut with a steel knife until a precise cutting edge is obtained. Images of the cutting area are then acquired with a resolution of 0,84 µm using incident light microscopy while the specimen is still mounted on the microtome. Cutting edges up to 2 cm can be analyzed.

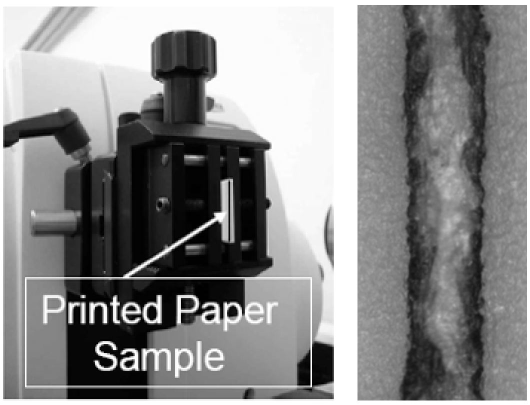

Fig. 2: Printed paper sample clamped between two plastic foils and mounted on the microtome.

The penetration depth is measured in the resulting image of the paper cross section using an image analytical software that was developed at the Institute for Paper, Pulp and Fiber Technology. Setting a simple threshold to detect the penetrated ink is not sufficient; therefore a *Color MSER* [14] algorithm was developed, which analyzes local colour distributions and identifies regions of penetrated ink. In the next step the penetration depth is measured and calculated from the resulting image. The values are evaluated statistically and the coefficient of variation of the penetration depth is calculated.

The advantages of this method over the prementioned techniques are the avoidance of embedding resin and the automated cutting and imaging procedure to yield highly reproducible results.

RESULTS

To evaluate the influence of ink penetration on the print quality a set of 8 rotogravure printed commercial SC-A paper samples was analyzed. The printing was performed under standardized printing conditions. First the ink penetration was measured with the previously presented microtomy method. Also print quality was evaluated with an image analytical algorithm named IASU (Image Analytical Structure Unevenness) [15]. IASU evaluates the quality of the print image and its uniformity and homogeneity. It provides the so-called IASU-Index as a result. A high IASU-Index stands for a heterogeneous, mottled print and a low IASU-Index describes a homogeneous print result. Additionally standard methods for paper und print testing were performed: penetration volume according to Cobb-Unger oil absorbency (SCAN-P 37:77) and print density using a Gretag Macbeth densitometer.

In the following the results of the penetration measurement of the printed SC-paper samples are correlated to the results of the different printability tests to describe ink penetration behaviour and its effect on the print result. The black full tone areas of the printed samples were examined.

In Fig. 3 the penetration depth is plotted against the colour density. The correlation shown would indicate that print quality increases with high penetration intensity. A similar result is obtained by correlating the ink penetration depth with the homogeneity of the printed image measured by IASU (Fig. 4) suggesting a positive influence of intense penetration on the print quality.

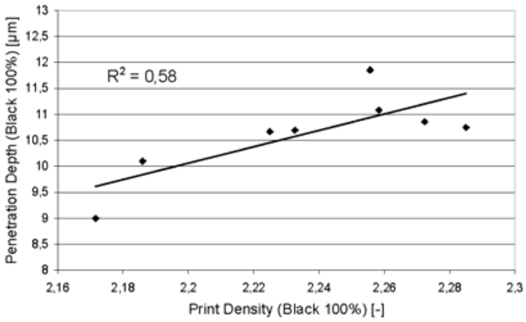

Fig. 3: Influence of the Penetration Depth on the Colour Density.

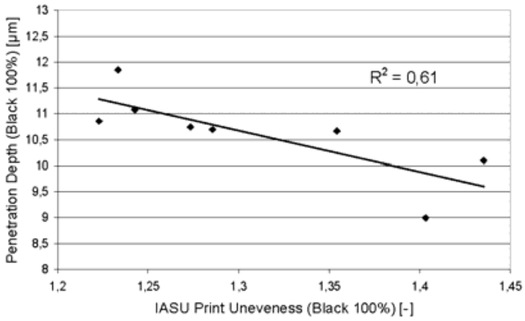

Fig. 4: Influence of the Penetration Depth on the Print Unevenness.

It was an unexpected result that the colour density and the homogeneity of the print improve with increasing depth of ink penetration. This finding can only be explained by the idea that penetration depth is not necessarily equivalent to the volume of ink penetrated into the paper structure (penetration volume). A paper with high porosity can thus still have low penetration depth. Our results indicate that penetration depth does not have to be the determining factor for the quality of printed full tone areas. There must be other parameters which have major influence on the print result as e.g. the penetration volume expressed by the Oil absorbency according to Cobb-Unger (Fig. 5). The correlation of the penetration volume with the colour density shows that the lower the capacity for fluid uptake, the higher is the print density. Also in earlier results [13] we have found that penetration depth and potential penetration volume (Cobb-Unger) are two mutually independent aspects of ink penetration.

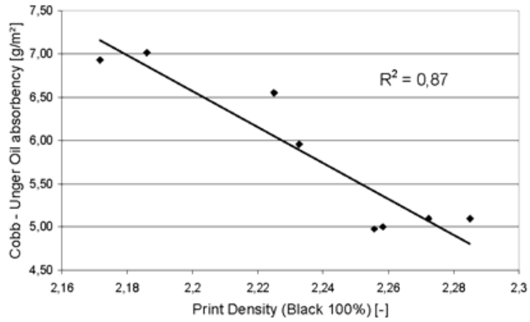

Fig. 5: Influence of the Penetration Volume on the Colour Density.

Furthermore the coefficient of variation of the penetration depth was calculated from the measured data to investigate the influence of inhomogeneity of penetration on print mottle. For this purpose the variation of the penetration depth was correlated with the colour density (Fig. 6) and the IASU Print Unevenness (Fig. 7). In both cases a negative influence of varying ink penetration on the print quality was found. With increasing variation the colour density and the uniformity of the print image are reduced. While it is straightforward that inhomogeneous penetration leads to uneven print, the correlation between penetration inhomogeneity and print density is not so obvious.

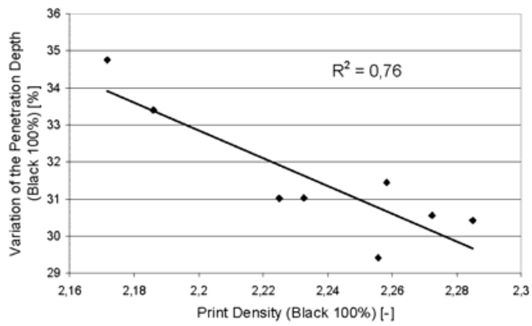

Fig. 6: Influence of the ink distribution on the Colour Density.

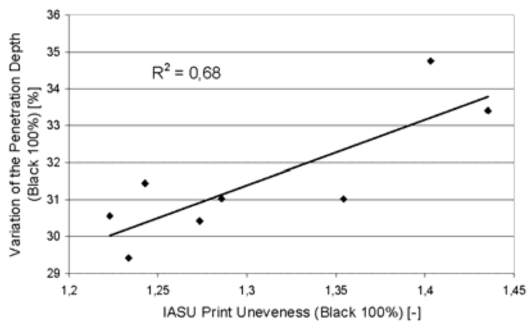

Fig. 7: Influence of the ink distribution on the Print Unevenness.

It may be explained by Fig. 8 which shows that the variation of the penetration depth increases with the absorbency of the paper. Papers with large penetration volume obviously also tend to exhibit more inhomogeneous penetration which could also be seen in [13].

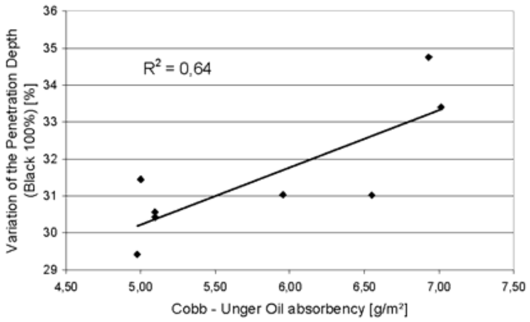

Fig. 8: Interrelation between Penetration Volume and ink distribution.

The results of our research show that even if the printing ink does not penetrate deep print quality can still be poor. This is caused by higher capacity for fluid uptake and by non-uniform arrangement of the pores in the paper structure, which leads to inhomogeneous penetration and finally to uneven print.

CONCLUSIONS

By correlating several parameters of SC-A papers to rotogravure print quality an influence of the variation of penetration depth and the oil absorption according to Cobb-Unger on the colour density and the homogeneity of the print image was found. The pore volume of the paper and the variations in the penetration of the printing ink determine the print result. Thus local variation of ink penetration turned out to be a much more relevant influence factor on both, print density and print homogeneity, than average penetration depth.

The cutting method using a rotary microtome is a suitable tool to measure the penetration depth of printed uncoated papers. It provides constant testing conditions and does not require paper embedding. For future research this method can also be applied for 3D-analysis of the paper using automated microtomy [16] to obtain information about the true 3-dimensional penetration structure.

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REFERENCES

[1] LAUFMANN, M., „Calcium Carbonat Fillers in SC-Papers“, Wochenblatt für Papierfabrikation 133(11/12):622-641 (2005).

[2] YANG, L. / FOGDEN, A. / PAULER, N., “A novel method for studying ink penetration of a print”, Nordic Pulp and Paper Research Journal 20(4):423-429 (2005).

[3] KLEMM, K.W., „Penetration Behavior of Inks into LWC and SC Papers and ist Impact on Drying“, Wochenblatt für Papierfabrikation. 127(6):397-400 (1999).

[4] ELTON, N.J. / HOOPER, J.J. / GANE, P.A.C., “Optical microscopy of paper methodology and applications” 24th EUCEPA Conference, Stockholm Sweden, 438-458 (1990).

[5] ERIKSEN, O. / GREGERSEN, O., “A study of ink penetration and optical properties of laboratory sheets using scanning electron microscope”, The 2004 Progress in Paper Physics Seminar, 216-218 (2004).

[6] SENDEN, T.J. / BAUER, A. / ROBERTS, R.J., “Experimental imaging of fluid penetration into papers”, Appita Conference 149-153 (2007).

[7] HEARD, P.J. / PRESTON, J.S. / PARSONS, D.J., “Visualisation of the distribution of ink components in printed coated paper using focused ion beam techniques”, Colloids and Surfaces A: Physicochem. Eng. Aspects 244:67-71 (2004).

[8] ENOMAE, T. / IVUTIN, D. / ISOGAI, A., “Three-dimensional distribution of ink-jet inks in paper acquired by confocal laser scanning microscope”, 58th APPITA Annual conference & Exhibition Proceedings 577-588 (2004).

[9] ASPLER, J. / JORDAN, B. / O’NEILL, M., “Gravure print quality of uncoated mechanical printing papers”, Pulp and Paper Canada 101(2):32-37 (2000)

[10] YANG, L. / FODGEN, A. / PAULER, N. “Studying ink penetration with microscopic and spectroscopic techniques”, The Journal of Imaging Science and Technology 50:327-332 (2006).

[11] LIPPONEN, J. / LAPPALAINEN, T. / ASTOLA, J., “Novel method for quantitative starch penetration analysis through iodine staining and image analysis of cross-sections of uncoated fine paper”, Nordic Pulp and Paper Research Journal 19(3):300-308 (2004).

[12] ENZI, S., „Skalpellschnittverfahren – Mess-methode zur Beurteilung der Druckfarbenpenetration bei SC-Papier“, Master Thesis, Graz University of Technology (2002).

[13] ENZI, S. / BAUER, W. / HIRN, U., „Einfluss der Penetration auf das Bedruckbarkeitsergebnis von SC-Papieren im Tiefdruck“, PTS Symposium Paper and Imaging 15.1-15.12 (2004).

[14] DONOSER, M. / BISCHOF, H. / WILTSCHE, M., “Color Blob Segmentation by MSER Analysis”, Proc. of International Conference on Image Processing (ICIP) 757-760 (2006).

[15] HIRN, U., Internal Report, Graz University of Technology.

[16] WILTSCHE, M. / DONOSER, M. / BAUER, W., „A New Slice-Based Concept for 3D Paper Structure Analysis Applied to Spatial Coating Layer Formation”, Proceedings 13th Fundamental Research Symposium Cambridge 853-899 (2005).