

A STUDY OF THE PROCESS OF INK PENETRATION INTO PAPER BY ELECTRON MICROSCOPY

Irina V. Nagornova¹, Larisa G. Varepo²

¹Moscow State University of Printing named after Ivan Fyodorov, Moscow, Russia

²Omsk State Technical University, Omsk, Russia

Abstract

Results of study of paper surface microgeometry, “ink-paper” interface and ink distribution inside paper pores on base cross-section SEM-images and 3D-images, obtaining by laser scanning confocal microscope are demonstrated. EDS-spectrums and elements distribution of selected areas present in ink film and paper compositions with various surface microgeometry are shown.

Quantitative evaluation of main parameters of surface microgeometry of different paper types was obtained.

Various nature of ink film distribution at the “ink-paper” interface defined by surface microgeometry and paper structure is presented. The depth of ink penetration inside paper pores was defined.

The ink penetration rate in view of surface profile parameters, depth of ink penetration, shape and pore size is calculated.

Key words: *ink penetration, electron microscopy, laser scanning confocal microscope, EDS, mathematical model*

INTRODUCTION

Reproduction quality of printed output originals is determined both by characteristics of materials taking part in printing process, in particular inks and materials – information carriers, and by parameters of technological printing process.

Irrespective of used printing process type, ink curing represents a set of complex processes the course of which is made conditional upon physical – chemical properties of interrelated systems. Complexity of phenomena taking place in printing zone is determined not only by the process of ink transfer onto paper but also by the escaping process of substrate from engagement zone which is accompanied by splitting down of ink film and structural characteristics of used materials.

The process of layer splitting, transfer of its part onto substrate and fixing process is complicated by many unexplored phenomena. The most complete and comprehensive study of ink transfer mechanism must necessarily be taken into consideration when forming processes of adhesive engagement as well as phase structure of ink film.

Understanding of the ink penetration complex mechanism during printing process is necessary for print according to ISO 12647-2 (State Standard of Russian Federation 52766) requirements and also for prediction of ink-paper (cardboard) interaction features.

In the study we determine the ink penetration as the property of a substrate (paper, in this case) to take the amount of ink during print process in the escaping moment from the nip zone of printing machine which is accompanied by splitting of ink film

According to the standard procedure, the ink penetration is defined by optical density of ink field with their one-, two-, three overlays taking into account their sequence. The main disadvantages are:

- high labor content of the procedure;
- surface roughness and ink penetration onto paper pores is not included;
- narrow assortment of offset paper types used for reference curves
- absence of reference curves for embossed and designer surface paper or cardboard.

Researches of ink penetration into substrates, quantitative evaluations of main parameters of surface microgeometry of different paper types (including embossed and designer paper) are initial data for developing of ink penetration calculating (prediction) methods and ink-substrate interaction process modeling according to surface microgeometry, porosity of the printing material, viscosity, depth of absorption, surface and bulk distribution of ink, pressure and contact time.

METHODS

The objects of study were output originals printed by using black ink TOYO Tianjin Ink Orion on different paper types with various surfaces microgeometry. Print machine Speedmaster SM-102 was used for print.

The shape and mutual disposition of paper pores, ink distribution on a paper surface as a result of ink-paper interaction in the escaping moment from the nip zone were investigated by traditional optical methods and also electron microscopy methods

Scanning electron microscopy with cross section sample preparation procedure was used for study of ink-paper interface inside of substrate. SEM-images were obtained by using field emission scanning electron microscope JSM7500F (JEOL) in secondary electron detecting mode with acceleration voltages 1, 10 and 15kV. Element analysis of surfaces was carried out by EDS-detector X-Max 80 (Oxford) with acceleration voltages 10 and 15kV, probe current $2 \cdot 10^{-9}$ A. Platinum layer coating (8 nm) was used to avoid destruction of samples.

The evaluating of substrate microgeometry parameters was carried out by using laser scanning confocal microscope **KEYENCE VK-9700 Generation II**. By laser scanning were obtained noncontact measuring of a 3D-coordinates sample profile surface (topography). High resolution and real color of sample is provided both by using short-wavelength laser and white-light source for lighting of a sample.

The programming language Visual C# and NET Framework 4.0 and the software environment Microsoft Visual Studio 2010 are used for developing of the Software to analytical represent of the surface profile and an estimate of its parameters [1].

RESULTS

For developing of evaluation method of ink penetration into substrate (paper, cardboard) we used a mathematical analysis technique. The sample is mathematically split on m parts. The surface of each part is approximated by cylindrical surface defined as

$$\varphi_i(x, z) = 0, i = 1, 2, \dots, m$$

A graph image of one single ink layer part is shown on figure 1.

We assume the mass of the ink on the sample consists of two terms M ,

$$M = M_1 + M_2$$

The first term is equal to the ink layer mass M_1 , overlying the deformed surface of the paper, and the second ones M_2 – ink is imbeded into the paper pores at an average depth of q flowing ink.

We assume the each point z applicate of these surfaces is a random variable in our coordinate system.

For estimate of ink layer mass M_1 we divide a paper sample by planes

$$y = y_i; i = 1, 2, \dots, m,$$

which are parallel to the coordinate plane XOZ with the step h .

In this case ink layer overlying the deformed surface of the paper is split on m parts.

As ink layer mass M_1 estimating we take value calculated by formula $M_1 = \rho V$.

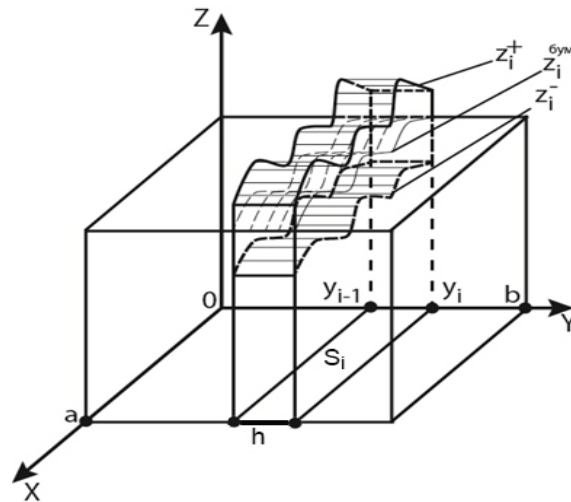


Figure 1 - A graph image of one single ink layer part

The volume of ink layer overlying the deformed surface of the paper we find through a triple integral formula:

$$V = \sum_{i=1}^m V_i = \sum_{i=1}^m \iiint_{V_i} dV_i \approx \sum_{i=1}^m \iint_{S_i} (z_i^+ - z_i^{6ym}) dx dy = \sum_{i=1}^m \int_{y_{i-1}}^{y_i} dy \int_0^a \sum_{k=1}^n \left((b_{ki} - c_{ki}) \sin \frac{\pi k x}{a} \right) dx =$$

$$= \frac{2ah}{\pi} \sum_{i=1}^m \sum_{j=0}^{2j+1 \leq n} \frac{b_{2j+1,i} - c_{2j+1,i}}{2j+1}.$$

which $b_{2j+1,i}, c_{2j+1,i}$ – coefficients of Fourier polynomial for cross sections profile z_i^+ и z_i^{6ym} .

We used 3D-images, obtaining by laser scanning confocal microscope (figure 2) to define a real topography of different papers (cardboards) types

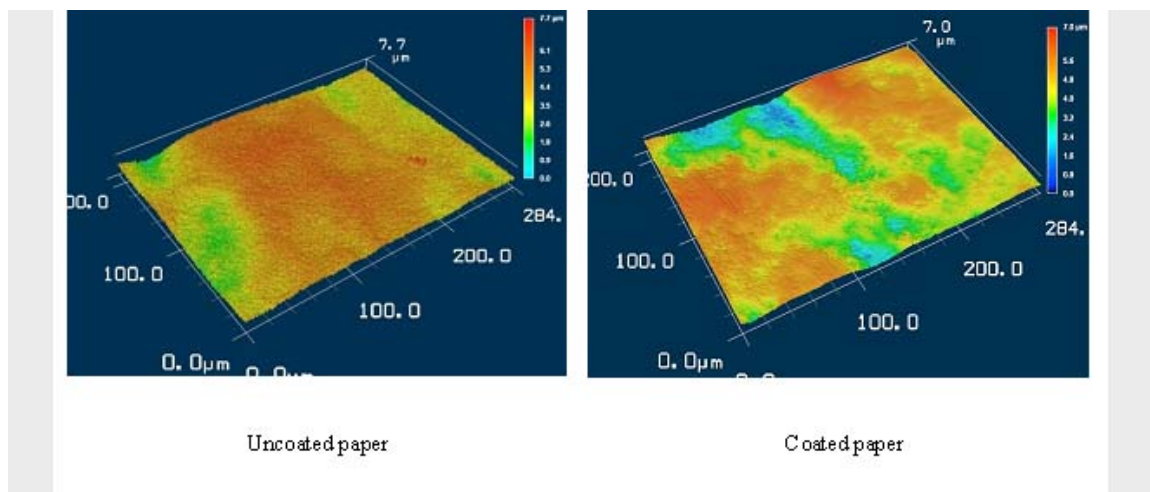


Figure 2 – 3D-imaged of print surface

As known, paper topography is a result of production and finishing processes and realizes in a random manner. Images are clearly shown irregularity of surface for all types of paper.

The software of laser scanning confocal microscope allows obtaining quantitative estimate of microgeometry parameters of surface. This data we used for evaluation of surface topography [1]:

$$S_n(x, y) = \sum_{k=1}^n b_k \sin \frac{\pi k x}{l}, \quad (1)$$

where coefficient b_k is

$$b_k(y) = \frac{2}{l} \int_0^l z(x, y) \sin \frac{\pi k x}{l} dx, \quad (2)$$

l – sample length, $z(x, y) = f(x)|_{y=c}$ – function of surface at fixed value y , (3)

The equation (1) was obtained by the following transformation:

- not periodic function of topography in cross section $y = y_i$ on interval $0; l$ was continued oddly stacked to the interval $[-l; 0]$;
- function obtained on the interval $[-l; l]$ (and at result, function on interval $[0; l]$) was represented as a polynomial Fourier sine (with any desired degree of accuracy).

The equation

$$M_2 = \pi \rho a b n q d^2 / 4, \quad (4)$$

are used for estimation of ink mass M_2 , where d – average diameter of pores, q – average depth of ink penetration into pores, n – quantity of pores on 1 cm^2 , a and b – size of paper sample.

The average depth of ink penetration into pores was defined by SEM-images.

SEM-images of paper (cardboard) cross section with various surfaces microgeometry – coated (a), textured (b), and polished uncoated (c) upper layers are shown on figure 3.

According to SEM-images some amount of ink is absorbed by material surface. This amount is determined by ability to retain in surface roughness and to penetrate into pores. Ink distribution character onto surfaces also depends on microgeometry of surface. It is clearly observed on SEM-images (figures 3, 4).

Ink penetration depth into substrates pores is more in the case printing ink onto uncoated and textured paper (cardboard) than for coated ones. Large pores are not filled ink completely, especially for material with strong surface relief (figure 4, c, d). The thickness of ink layers is from 0,5 to 2,5 μm . The deviation of thickness is more for textured paper (cardboard) (figure 4, b-d).

Using cross sections of printed materials with various surfaces microgeometry we have obtained elements distribution images and x-ray spectrums in different points of ink-substrate interface. The distribution of elements which included in ink formulation on surface and in volume of materials is shown on figures 5. EDS-spectrums and element mapping (for carbon and oxygen) of selected area for textured and coated paper are represented on figure 5, to. On SEM and EDS images are clearly seen ink layers.

Images are demonstrated that ink concentration and penetration into microporous of coated paper are higher and homogeneous comparing ones for macroporous structure of textured and uncoated paper.

By change in equation (4) q (average depth of ink penetration) to

$$q = \pi d \sqrt{\frac{P t}{\eta}},$$

where P – pressure in nip zone, t – contact time, η – viscosity of ink

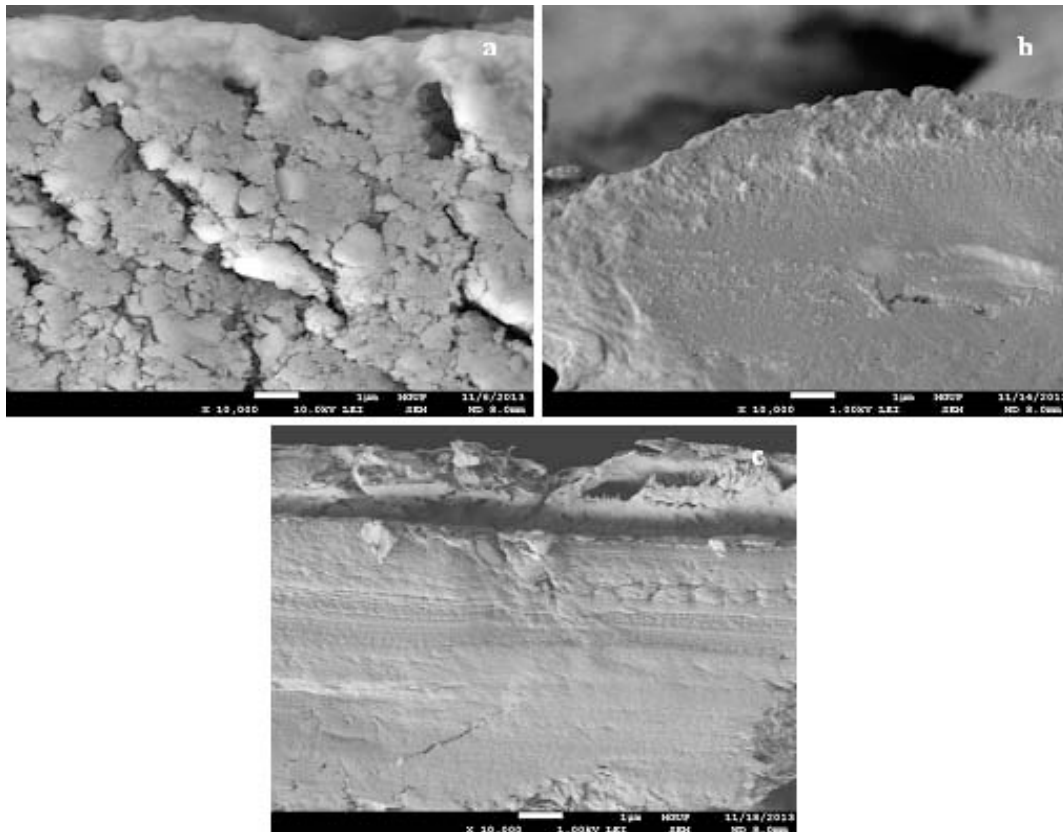


Figure 3 - SEM-images of paper cross section with coated (a), textured (b), and polished uncoated (c) upper layers

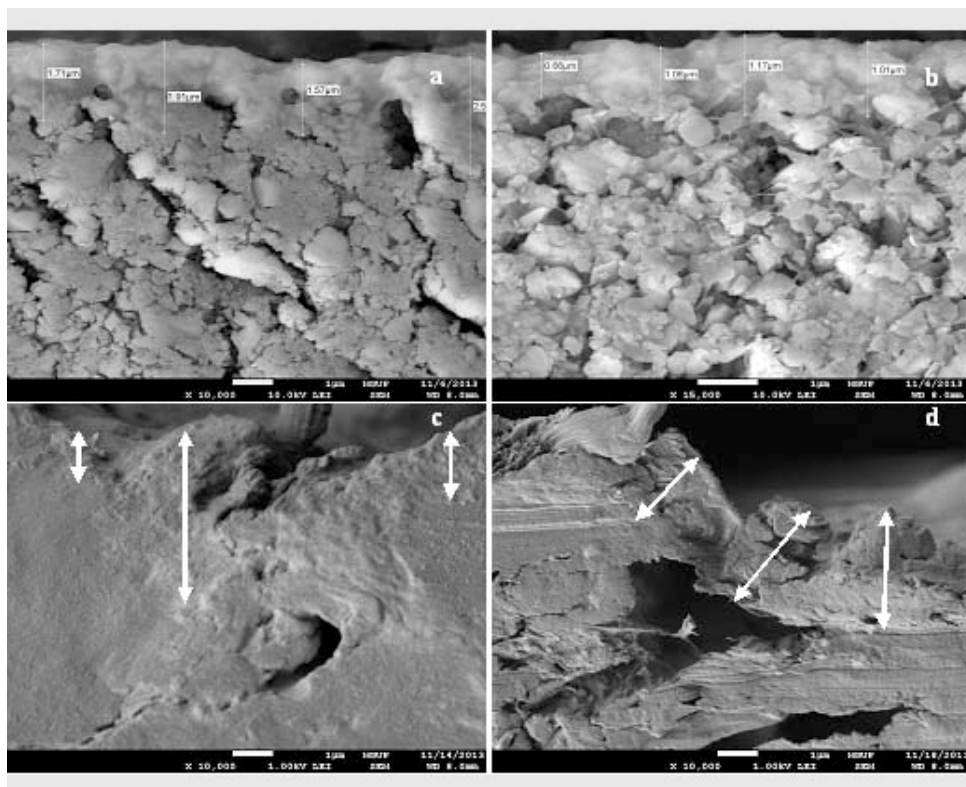


Figure 4 – Ink penetration into substrate with (a, b) coated and textured (c, d) uncoated upper layers

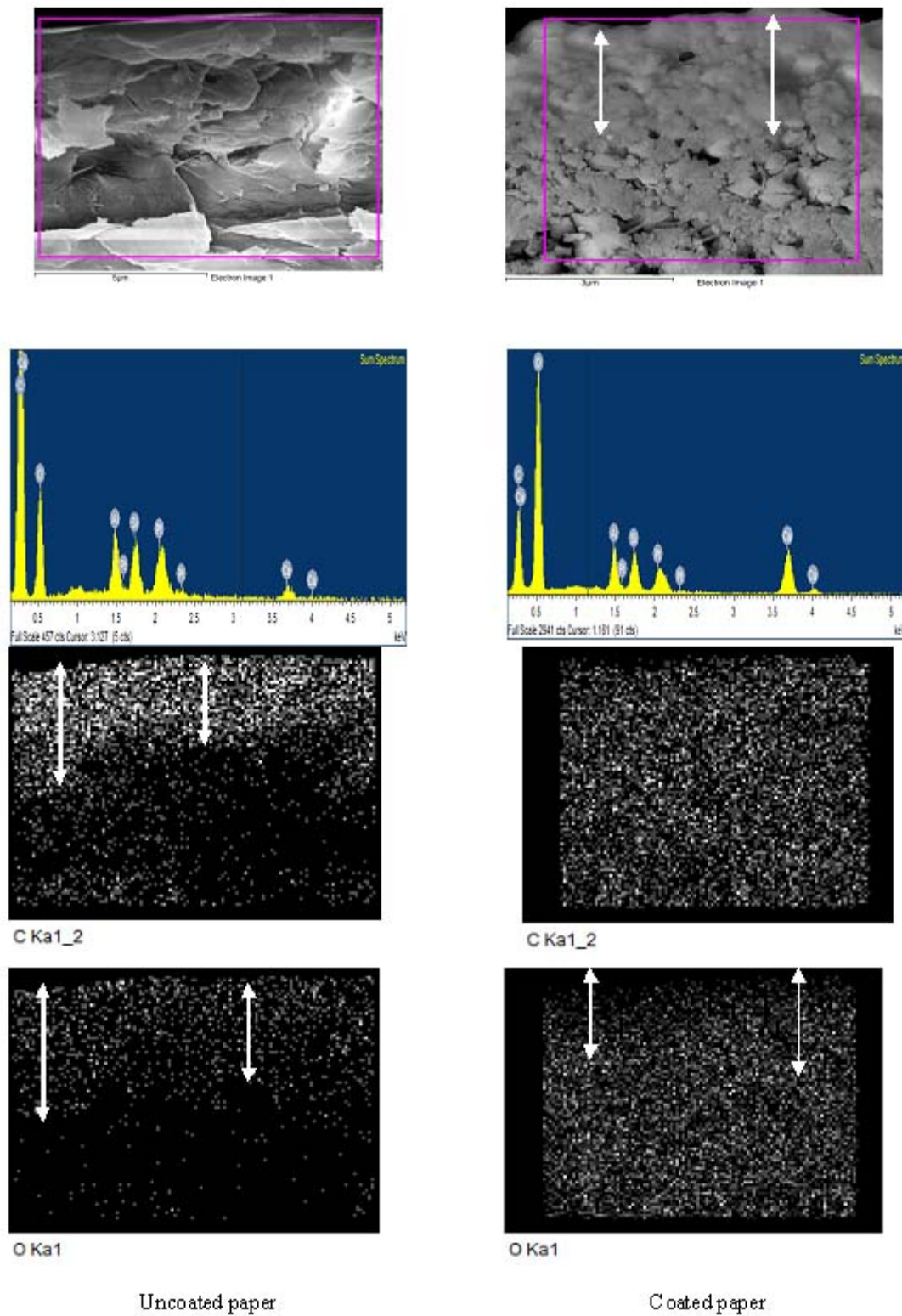


Figure 5 – Ink elements distribution into substrate structure

and taking into account sinuosity χ and non cylindrical character of pores ξ (see figures 3 and 4) we obtained analytical estimate (model) of ink penetration for print sample (paper, cardboard):

$$M = \rho \frac{2ah}{\pi} \sum_{i=1}^m \sum_{j=0}^{2j+1 \leq n} \frac{b_{2j+1,i} - c_{2j+1,i}}{2j+1} + \frac{1}{4} \pi^2 \rho a b n_p \left(2 \cdot \frac{h^2 2\eta \chi^2 \xi^2}{t \sigma \cos \theta_p} \right)^3 \sqrt{\frac{Pt}{\eta}}. \quad (5)$$

where σ – coefficient of surface tension; θ_p – the equilibrium contact angle.

The model is adequate according the Fisher test with confidence level 0,95.

Based on represented mathematical model was developed software for quantitative estimate of ink penetration for print materials [2].

CONCLUSIONS

We have constructed and investigated picture of ink penetration for print samples using microscopy methods. We developed and tested method of quantitative estimate of ink penetration for print materials based on mathematical model taking account surface topography, porosity of material, viscosity of ink, depth and character of ink penetration, pressure in nip zone and contact time.

We have demonstrated features of ink penetration for different types of paper.

We have developed software (patented) for using in polygraphic and packing manufacturing as alternative method of quality control and possibility of operative testing of ink penetration for different materials.

REFERENCES

1. Варепо, Л.Г., Борисова, А.С., Колозова, О.А. Аналитическое представление оценки профиля поверхности материалов для печати. *Известия высших учебных заведений. Проблемы полиграфии и издательского дела*. 2010, № 5, с. 16-23.
2. Варепо, Л.Г., Борисова, А.С., Колозова, О.А., Трапезников, Е.В. Программа для оценки красковосприимчивости запечатываемого материала. *Свидетельство о гос. регистрации программы для ЭВМ №20111618158* от 18.10.2011 г. М. : ФИПС, 2011.