Application of Modern Physical Research Methods for the Technological Process Control of the Accurate Printing

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Keywords: Accurate printing, security printing, quality control of the printing plates, physics of the surface analysis

In the context of today's globalization of industry, the growing importance of the authenticity of printed information, documents with special security marks and various other objects and products has been observed. Currently, a wide range of graphics solutions characterised by high resolution (20–40 µm) of printed elements are used to protect printed production. In order to meet high quality requirements, special printing equipment, advanced technologies and appropriate properties of materials are required. Advanced printing technologies enable to achieve reproducibility and resolution of the elements up to 25–30 µm, and this provides an opportunity to apply complex graphic solutions that would restrict copying or reproduction. It has become an inseparable part of production of banknotes, securities, documents, trademarks, special purpose markers and packaging production for authenticity purposes. Yet, the quality of the product depends on the preparation process, including technologies and materials applied in the production of the printing plates that provide a high image resolution. To print elements of the extremely small dimensions, accurate area of the printing element and thickness of the ink layer play an important role, meanwhile accuracy of the geometrical dimensions of the printing elements is related to the morphology of the printing plate surface. Based on current requirements for the accurate printing and its technologies, regular metrological control tools are not adequate for printing control. Therefore, it becomes necessary to use physical control methods applied in other areas, such as materials science and semiconductor physics.

1. Introduction

The term 'accurate printing' or 'security printing' has emerged together with the need to protect authenticity of the specialty printed production. The current era, as never before, is facing issues of counterfeit of personal identification documents, banknotes, securities, government documents, brand labels, packaging. In terms of the offset printing, modern advanced technologies enable to form high-resolution printing elements such as: guilloche elements, micro text, latent images, complex 3D background images, barrier elements limiting copying and so on. The function of the graphic solutions can be realised only by high resolution printing technology, e.g. accurate printing [5, 1]. Offset designed for long-run security printing has been known as the most accurate and most appropriate printing technique so far. Also, there have been other accurate printing techniques, yet there are not applied for mass production of documents with special security marks.

As it is known, in the offset printing ink is transferred on the several surfaces such as printing plate, offset blanket and paper. Morphology of each surface affects the quality of the ink transfer onto the print and accuracy of the geometric dimensions. It is evident, that formation of the ink coating is determined by a number the technological and materials characteristics: conditions of the process environment, quality of the printing plates, viscosity of the inks and other rheological properties, characteristics of print materials and morphology of the surfaces, ink transfer, surface morphology and its free energy, dampening parameters, dynamics and kinematics of the printing process.

Resolution of the print as well as its reproducibility depends on quality of the printing plates, too. Structure of the offset printing plates is not homogeneous, in general, it is a multi-layered structure, which surface is covered with a thin (0.5–1 µm) polymer layer with its own specific characteristics that affect accuracy of the ink layer transfer. Relatively minor inequalities on the surface of the printing plates, can result in edge unevenness of the printed element, and thus determine precision and quality of the whole image.

Positive printing plates produced by different producers were analysed here. The polymer layer on the surface of different plate's samples was analysed and measured before exposure. The polymer layer on printing areas of positive plates do not alter during the exposure (laser affects non printing areas).

The research does not claim to be comprehensive; it has been limited to the analysis of the printing plates' properties and the possible impact on the accuracy of the graphic elements.

Ink layer thickness *d* applying the offset printing, usually ranges within 0.3÷5μm limits. It is evident, that printing high-resolution elements which width is *b* = 25–5 μm, the thickness of the ink layer *d* will be minimal, up to a few hundred nanometres. Distribution of the layer thickness should not exceed Δ*d* ≤ 0.05 *d* limit. Formation of the ink layer of such extreme thinness and width is limited by three major complex factors: viscosity of the inks and their rheology, accuracy of the geometric dimensions and physical characteristics of the materials of the printing plates, properties of the print materials and morphology of the surface. It is clear, that accuracy of the geometric elements of the prints is determined by quality of the printing plates. For a couple of decades, this parameter was measured applying a vacuum change method. Recently, profilometers are used to measure changes in the surface morphology within 0.2 – 1 μm limits. Yet, it cannot ensure an accurate analysis, when thickness of the polymer layer on the printing plates is the same. Thus, it becomes necessary to use more accurate methods of physical control which are applied in other areas, e.g. materials science or semiconductor physics. For example, an atomic force microscopy detects 10 - 6 mm geometric changes, which in turn, enables to assess extreme values of the surface inequalities, its nature of change and frequency [6].

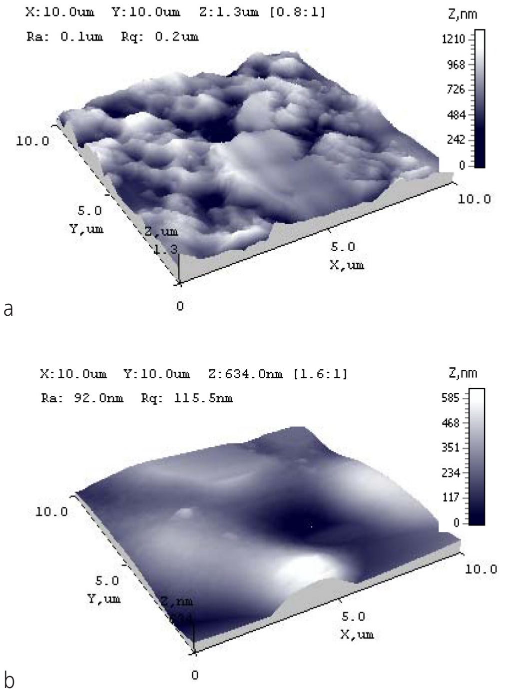


Figure 1: Fragments of the surface morphology – a) FUJI VPS-E; b) AGFA Energy Elite PRO

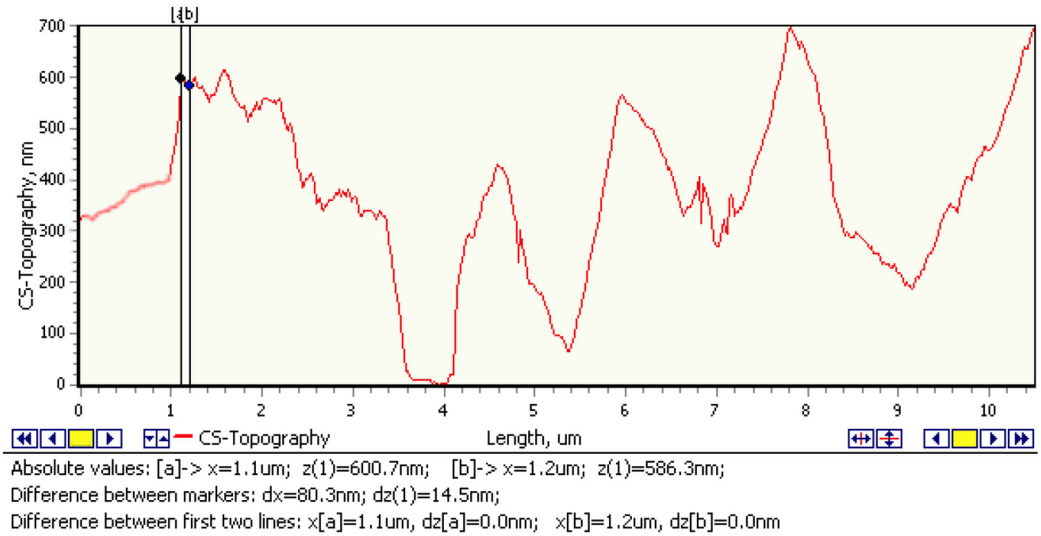
2. Sample analysis and results

Experimental analysis of the metrological method was carried out using an atomic force microscope (model NT-206), major characteristics: z_{max} = 4 μm, lateral resolution: 2 nm, vertical resolution 0.1–0.2 nm. Analysed samples: FUJI VPS-E offset printing plate for the positive technology λ = 400 nm and AGFA Energy Elite PRO offset printing plate for the positive thermal technology λ = 830 nm. Scanned fragments of the AFM printing plate samples and their surface morphology are presented in Figure 1.

Scanned fragments of the surface morphology of the printing plate samples using AFM, identify size and nature of the relief micro inequalities of the printing plates. Extreme value of the surface of the FUJI VPS-E printing plate is z_{max} = 1.21 μm, and the extreme value of the AGFA Energy Elite PRO printing plate z_{max} = 0.585 μm (Figure 1). Scanned surface of the samples employing AFM (Atomic Force Microscope) is 10 × 10 μm. Generalised sizes are used for assessment of the surface morphology. The most widely used size is R_a, an arithmetic mean of the overall height of the surface inequalities. As the obtained results of the sample measurement show, FUJI VPS-E R_a = 0.1 μm, AGFA Energy Elite PRO R_a = 0.09 μm. The atomic force microscope employed mathematical algorithm to calculate the average surface inequalities' R_a values, which differ from extreme values of the measured surface. If smoothness of the surface is treated as mathematical average of the extremes, it can be assumed that the surface state is not sufficiently defined. Measurement results of the printing plates FUJI VPS-E and AGFA Energy Elite PRO surface inequalities demonstrate that the discrete roughness values are significantly larger than the thickness of the formed inks' layer, which under the conditions of the accurate printing may be d = 0.2–0.4 µm. High-resolution prints (and not only) may contain local defects, rough areas on the printed element edge and interruptions of thin line.

Absolute sizes z_{max} / z_{min} of the printing plate surface inequalities will influence the quality of formation of the thin ink layer on the print as well as on its distribution on the surface of the printing plate. In the case of linear contact between two surfaces with mutually equal free surface energy, a thin layer of ink at the moment of division splits into approximately two equal parts [2], yet, a significant impact on the effective area of the surface is determined by the surface morphology. It means that, surface morphology of the printing plates / forms (micro inequalities) will have a substantial impact on the thin ink layer d = 0.2–0.4 µm formation on the printed surface.

In positive offset printing plates, a top coat layer transfers printing inks on an offset cylinder. Therefore,



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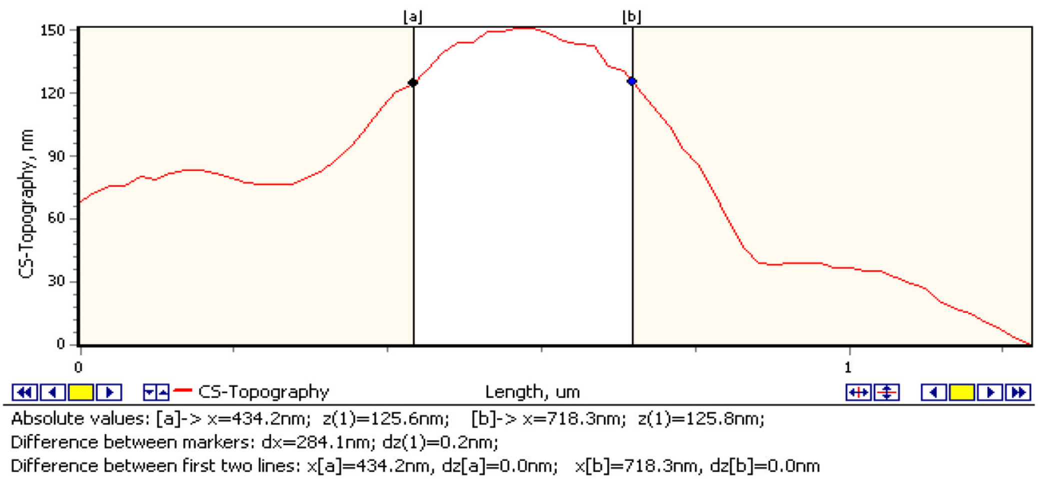

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Figure 2: AFM profilogram of the printing plate surface – a) FUJI VPS-E; b) AGFA Energy Elite PRO

the coat's surface morphology of the printing plates will affect uniformity of the ink layer thickness. In order to evaluate the surface morphology, it is necessary to take into account the nature of micro inequality distribution. Measurements of the profilograms of the printing plates FUJI VPS-E and AGFA Energy Elite Pro surface morphology using AFM NT-206 are presented in Figure 2 as shown using direct measurement readings of the device on different scale. Outcomes of the research show that significant differences of the sample surface morphology have been determined. Frequency rate of the FUJI VPS-E printing plates surface micro inequalities' extremes is greater than in AGFA Energy Elite Pro printing plate; difference in the adjacent extremes' values is significantly bigger and reaches 0.4–0.5 μm. Meanwhile, the Energy Elite plate AGFA PRO value is lower by 0.15 μm. Measurement results using AFM confirm that the generalised evaluation of the micro inequalities' surface height is

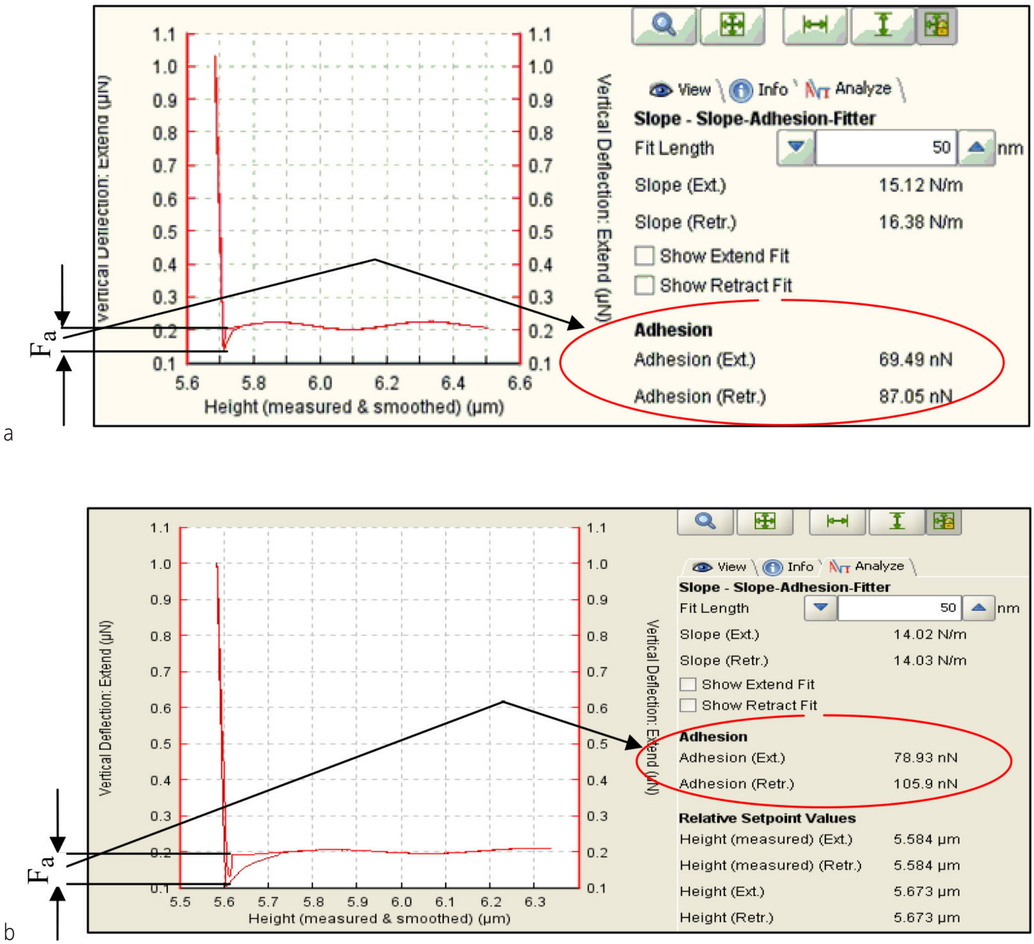


Figure 3: Adhesion force Fa measurement of the printing plates' surface using AFM – a) FUJI VPS; b) AGFA Energy Elite PRO

expressed using R_a, which is inadequate to characterise the concept of the surface smoothness.

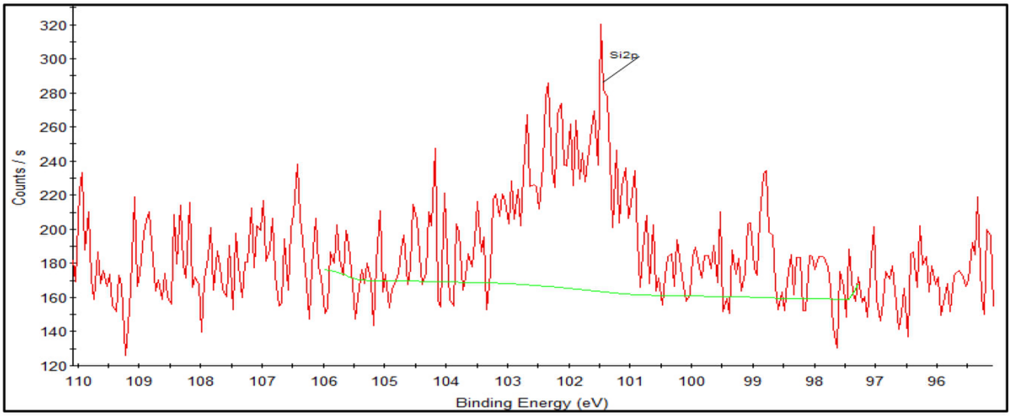
In the process of ink transfer on the surface of the print and uniformity of the layer thickness, adhesion force of the contacting surfaces plays a significant role. Liquid ink adhesion force with the surface is proportional to the surface energy. AFM method used for the surface analysis enables to evaluate the surface adhesion force F_a. The adhesion force is determined by analysing sensitive microprobe retraction/extraction curve slopes and amplitude variations (Figure 3). Measurement sizes (shifts of the probe) obtained using the AFM are direct measurement readings of the device as shown in the charts (the device determines initial data capture values, extension and retraction coordinates, therefore scale gradation as shown in the charts does not start from zero point).

Surface adhesion force F_a of the analysed printing plates' surface difference is as follows: FUJI VPS – F_a = 69.49 nN; AGFA Energy Elite PRO – F_a = 78.93 nN. After comparing the results it has been determined that surface adhesion force of the thermal printing plates is bigger by 11.9 %. In this case, the absolute measurement value is not sufficient to relate adhesive properties of the printing plate material to surface morphology. While assessing the process of the ink layer formation, relative adhesion should be expressed as a force per unit length. Applying probe method to measure adhesion $A = F_a / 2\pi R$; where R is probe radius. In Atomic Force Microscopy radius of the probe R is extremely small sized, since the sensitivity of the probe is measured by nanometres. Therefore, to assess the material surface adhesion for AFM is relatively problematic. In this case, adhesion force of the specific material/surface is assessed.

Adhesion plays a very important role in the printing process. The adhesion force determines distribution of the printing inks on the surface, thickness of the ink layer and its uniformity, uniformity of the inks separation from the surface, limit capabilities of the discrete elements of minimum geometric dimensions. In the offset printing, inks are transferred on several surfaces. The last three pairs of the contacting surfaces determine quality of elements, accuracy, and reproducibility. The surface adhesion of the material of the printing plates should be properly selected to ensure adequate proportion of the inks' thickness for consistent transfer/separation process.

Weak adhesion force is determined by low surface energy and lack of hydrophilic properties of the surface and chemical composition of the material, respectively. Chemical elements have different impact on the surface adhesion. For example, Na increases the surface energy, meanwhile Si, conversely, decreases. Oxygen compounds on the surface of the material form low-energy oxide film [4]. Chemical admixtures present in the material's matrix on the surface of the printing plates' coating determine adhesion of the inks with the contact surface. To analyse chemical composition of the element, X-Ray Photoelectron Spectroscopy XPS was chosen, since this test method is based on the law of external photoelectric effect. The method is designed for qualitative and quantitative analysis of the surface's elemental composition. The analysis of the detailed XPS spectra of the sample determines quantitative composition of each element and its relative atomic concentration, respectively. The research was carried out using ESCALAB- 250Xi (Thermo Scientific, England), FUJI VPS and YP-Q (China) to analyse samples of the violet laser technology printing plates. Surface morphology of both samples was measured using AFM NT-206, and as the outcomes of the research demonstrate, the obtained results were similar. It means that adhesion of the printing plates surfaces' may be determined by matrix of the element composition and concentration of the chemical admixtures present in the element. Spectroscopy was applied for Na and Si spectra exclusively. Results of the analysis show that Na atomic concentration in both samples was relatively identical approximately 2–3 %, yet Si atomic concentration significantly differed (Figure 4).

Atomic Si concentration in the plate FUJI VPS is 0.4 %, meanwhile in the plate YP-Q atomic concentration of Si element is 4.2 %. As it was mentioned above, Na increases adhesion of the material, and Si reduces. XPS spectroscopy has determined that in both samples Na atomic concentration is almost identical, thus impact of this element on the printing plates is the same, yet Si atomic concentration differs as follows: 0.4 and 4.2 %. It is possible to draw a conclusion, that adhesion of the printing plate's FUJI VPS surface should be bigger. It is confirmed by previous adhesion force measurement, using AFM – adhesion force of FUJI VPS printing plate F_a= 69.49 nN, adhesion force of the printing plate YP-Q (China) F_a= 51.05 nN. Based on correlation of the two analysis methods, it can be claimed that characteristics of the two printing plates, produced by different producers may differ, yet their technologies are the same.



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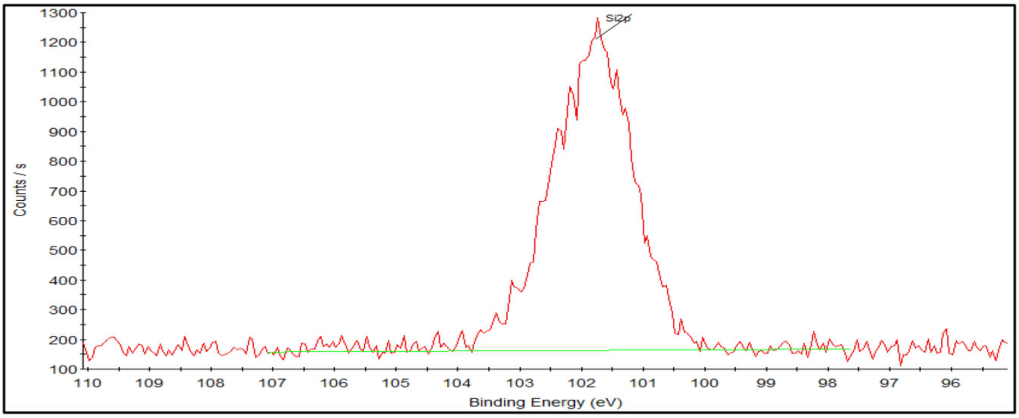

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Figure 4: XPS of Si spectrum of the printing plates – a) FUJI VPS; b) YP-Q (China)

3. Conclusions

In the accurate printing, formation of limit resolution of the discrete elements, reproducibility of the element dimensions and uniformity of the ink layer's thickness are determined by physical characteristics of the paper surface/printing plate. These factors have a significant influence on formation of elements of 20–40 micron line width and inks' layer thickness of 0.2–0.4 μm. To form elements of such accuracy, the arithmetic average of the inequalities of the surface on which inks are transferred, should be at least twice smaller than the thickness of the formed ink layer. Absolute values of the micro relief extremes of the surface and their nature of the spatial distribution determine uniformity of the layer thickness and minimisation of the local defects. Surface adhesion which depends on the surface interaction with inks, its chemical composition and partially surface morphology plays a vital role in determining accuracy of the element dimension formation and quality of covering the surface with inks, respectively.

Based on current requirements for the accurate printing and its technologies, regular metrological control tools are not adequate for printing control. Image fragments, individual discrete printing elements of high resolution, graphic prints, geometric reproducibility require modern physical analysis of the surface and chemical composition control methods.

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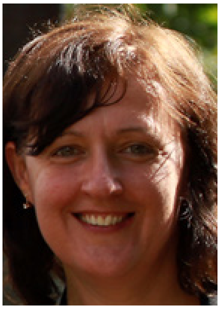

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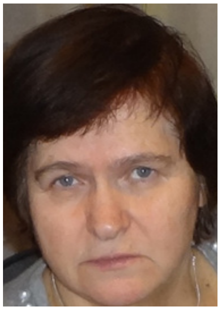

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