Original scientific paper
http://doi.org/10.24867/JGED-2022-2-029

Quality assessment of offset thermosensitive printing plates

ABSTRACT

This article discusses the technological possibilities of assessing the quality of offset thermosensitive printing plates by studying the influence of the structural and physical properties of their construction layers, as well as the parameters of digital computer-to-plate recording on the quality of formation and reproduction of image elements.
The article presents an original conceptual model for determining the integral quality indicators of printing plates, taking into account their structural and physical properties, a set of modern methods for evaluating the quality of offset printing forms is presented, such as evaluating the surface morphology of polymer registering layers and a substrate – a basis of the printing form; assessment of the adhesion of polymer layers of offset printing plates to the substrate surface, taking into account the influence of image recording parameters; investigation of the influence of the chemical state of the registering layers of offset plates on the adhesion of printing elements to inks; assessment of the influence of the processes of thermal action of laser radiation and the temperature gradient on the surface structure of the polymer layer of a thermosensitive plate and the accuracy of the formation of the quality of discrete image elements on printing plates. These researches are aimed at determining the relationship between the structural and physicochemical properties of offset thermosensitive plates and integral indicators of the reproduction quality of raster and line image elements in a digital recording system.

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First recieved: 16.12.2021.
Revised: 20.2.2022.
Accepted: 17.3.2022.

KEY WORDS
Offset thermosensitive plate, printing plate, surface morphology, adhesion, reproduction-graphic properties

Introduction

Determination of integral quality indicators of printing plates taking into account their structural and physical properties

Despite the rapid development of digital printing technologies, flat-bed offset printing using printing plates continues to occupy a significant part of the European market of printing products. The possibilities of using modern offset technologies allow printing high-quality paper and cardboard packaging, books, magazines, various graphic and advertising products, special products with signs of protection against counterfeiting and copying, which requires increased accuracy of graphic elements reproduction (Bobrobodro, 2010; Patlah, 2007; Khadzhynova & Havenko, 2020).

As is known, the physical parameters of the construction layers of the printing plates have a direct impact on the quality of reproduction of binary image elements on printing plates in the process of their digital recording in the Computer-to-plate system (Sevryugin, 2016). In particular, the thickness and chemical composition of the polymer layers of printing plates, the morphology of the surface of their polymer layers and the substrate, the adhesion strength of the polymer layers to the substrate and the adhesion of printing elements on the plate's surface to the ink layers have a direct effect on the printing plate run time and the ink transfer process during printing.

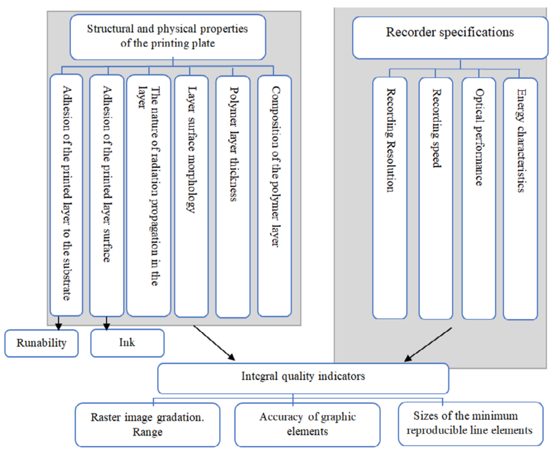
Along with the structural and physical properties of offset plates, the quality of image recording is influenced by integral quality indicators, in particular, the gradation transmission of the image, its range, the accuracy of reproduction of graphic elements, the size of the minimally reproducible line elements, etc. Integral quality indicators take into account not only the structural and physical properties of the construction layers of printing plates, but also their technological capabilities in conjunction with the platemaking equipment used for recording (Chepurna & Komarnytska, 2018).

Thus, the determination of the complex of physical, structural and integral properties of offset printing plates that affect the quality of finished printing plates is an important research process. Determination of indicators of these properties makes it possible to predict the quality of printing plates, which in turn makes it possible to make a targeted selection of plates for a specific production process at offset printing enterprises and to achieve optimal image recording quality in the "Platemaking device- printing plate" system.

The main characteristics of offset plates are determined by the sensitometric and reproductive-graphic properties of their polymer layers (Andreev & Sevryugin, 2012). The reproduction-graphic properties of the offset printing plate process are considered in (Kartasheva, 2008). The factors that determine the sensitometric and reproductive-graphic properties of the plates are the structural and physical parameters of the polymer layers that record the image: their thickness, nature and chemical composition, surface microgeometry. In particular, the thickness and chemical composition of the polymer layers determine the nature of the propagation of radiation in the layer, thus affecting the quality of the binary image recording. The morphology of the surface of the polymer layer of the plate affects the accuracy of the formation of image elements and the evenness of their edges. Comparison of the quality of the processes of recording images on light- and termosensitive offset plates, considered in the work (Andreev & Sevryugin, 2012).

The structural and physical properties of the polymer layers and the substrate of the plate also determine the technological capabilities of the printing plates in the printing process. The nature of the propagation of radiation in the polymer layer and the microgeometry of the wafer substrate surface also affect the degree of reflection of radiation and the adhesion of the printing elements to the substrate, therefore, determines the stability of the printing elements in the printing process and plate runability. The chemical composition and microgeometry of the surface of the polymer layer of the printing plate determine its surface energy and adhesion on the surface of the printing elements, therefore, influences the ink transfer process during the printing process.

Obviously, the main reproductive-graphic indicators of the quality of line and bitmap images reproduction on printing plates, such as the gradation transmission of the image, the resolution and excretory ability, the accuracy of reproduction of graphic elements, the sizes of minimally reproducible elements on recorded priting plates and others, are determined not only by the structural and physical parameters of their polymer layers. These quality indicators can be called integral, since they assess the quality of printed plates by a set of parameters. Integral quality indicators take into account the structural and physical properties of the construction layers of printing plates, their technological capabilities, together with the platemaking equipment used for recording (Figure 1).



» **Figure 1:** *Conceptual model for determining the integral quality indicators of printing plates, taking into account their structural and physical properties*

The above-mentioned indicators of image reproduction quality are also influenced by the parameters of recording systems – energy, optical characteristics, recording speed and resolution, etc. That is why it is so important to determine the integral indicators of the quality of printing plates, taking into account their structural and physical properties, which are characterized by the surface morphology of the layers of printing plates, adhesion of the polymer layer to the substrate and its chemical state under the influence of thermal effects.

Methods for determining the physical properties and integral quality indicators of offset printing plates

To determine the structural and physical characteristics of printed plates, it is advisable to use the following methods: atomic force microscopy (AFM) or surface free energy (SFE) method to determine the surface morphology of polymer layers and the adhesion force on the surface of the printing elements; the method of separating polymer layers using a needle (indenter)- to determine the adhesion strength of the polymer layer, and therefore the printing elements to the surface of the plate substrate; method of X-ray photoelectron spectroscopy (XPS)- to determine the chemical state of the surface of the layers. The nature of the propagation of radiation in a layer can be described using the method of physical modeling of laser processing of thin films, which makes it possible to assess the influence of the processes of thermal action of laser radiation and the temperature gradient on the surface structure of thin polymer layers and on the formation and quality of reproduction of image elements.

For the most detailed description of the **surface morphology** of the layers of printing plates, their microgeometry and roughness, it is necessary to use the parameters R_a – the arithmetic mean deviation of the microroughness profile, R_q – the standard deviation of the profile, and R_{max} – the maximum deviation of the profile height. To assess the morphology of the surface of the polymer layer and the substrate of the plates, we used the method of laser scanning on an AFM NT-206 microscope. According to the measurement results, profilograms of the surfaces of the layers and the arithmetic mean values of the R_a profile, the standard deviations of the R_q profile and the values of the maximum microroughness R_{max} were obtained (Margelevičius, Sajek & Kartasheva, 2015).

Determination of **adhesion on the surface of polymer layers** can be correctly performed using an AFM NT-206 microscope. As is known, the value of the adhesion force of the surface of printing plates is influenced not only by the properties of the microgeometry of the surface of the polymer layer, but also by its surface energy: the lower the surface energy, the weaker the wetting and adhesion on the surface of the printing elements of the plate. With increasing surface energy, wetting and adhesion increase. The magnitude of the adhesion force is largely determined by the properties and chemical composition of the polymer. Chemical elements in its composition affect the magnitude of the adhesion force, for example, the presence of sodium (Na) in the composition of the polymer in a certain amount increases its surface energy, and the presence of silicon (Si), on the contrary, leads to its decrease. Oxygen compounds on the polymer surface form oxide films with low surface energy. Chemical elements and impurities in the composition of the polymer layer of the plate determine the adhesion properties of the surface of the printing plate, which is in direct contact with the offset ink during the printing process (Margelevičius, Sajek & Kartasheva, 2015).

To determine the forces of **adhesion of the polymer layer to the substrate** of the printing plate, the method of layers separation was chosen in the framework of the research, i.e. scribing with a needle (indenter) with variable load and registration of normal F_N and tangential F_T load forces on the RA-120 device. When the indenter is deepened into a thin (1–2 µm thick) polymer layer of the Agfa Azura printing plate, at the moment of destruction of the coating, the value of FT becomes constant, i.e., the value of the indenter load is fixed, at which the coating peels off (Margelevičius & Sajek, 2010; Sajek & Kartasheva, 2017).

To carry out the process of analyzing **the chemical state** of the polymer layer of the studied plate, the X-Ray Photoelectron Spectroscopy XPS method was chosen using an ESCALAB-250Xi spectrometer. This is a quantitative and qualitative spectroscopic method for studying the elemental composition, as well as the chemical and electronic state of atoms on the surface of the investigated material. Broad (survey) and detailed spectra for qualitative and quantitative analysis of polymer surfaces were obtained by irradiating the surface of samples of Agfa EEP, Fuji VPS and YP-Q printing plates with X-rays (Sajek, 2018).

The method of studying **the processes of the influence of heat** and temperature gradient on the formation of graphic elements in the polymer layer of the printed plate was developed on the example of negative thermosensitive plates Agfa Azura. To study the effect of the type and parameters of thermal action on the structure of the latex surface on the platemaking device Heidelberg Supraseter A74 Agfa Azura printing plates with an IR laser power from 70 mW to 100 mW were recorded. Mathematical description of changes in the surface state of a layer of thin (0.5- 1 µm) latex film depending on the energy parameters of IR laser radiation- power and duration of exposure, is based on the physical model of laser processing of thin films.

The temperature of the film under these conditions (heat dissipation from the film of the polymer coating to the substrate is insignificant, the pulse duration is less than 10^{-7} s, layer thickness not more than 5 µm) is calculated using the equation:

$$T = \frac{q_0 A \tau}{\rho c h} + T_0 \tag{1}$$

where: q_0 – radiation power density, W/m²; A – the latex absorption coefficient $A=(1-R)$; R – the reflection coefficient; τ – the pulse duration, s; ρ – the density of latex, kg/m; c – specific heat capacity of latex, J/kg·K; h – layer thickness, m; T_o – ambient temperature, K.

When recording termosensitive plates, the largest part of the energy of thermal radiation is spent on the formation of an active printing element, but the edge of this element does not coincide with the edge of the distribution of thermal energy. Part of the energy is diverted outside the element, forming a blur zone and leading to its distortion. Obviously, the nature of the distribution of thermal energy has a direct impact on the accuracy of reproduction of active printing (in the case of a negative) and blank (in the case of a positive process) elements. The distribution of thermal energy in the layer proceeds from the areas exposed to thermal energy within the pixels towards the areas not exposed to laser radiation. This process is described using a temperature gradient:

$$T(x) = f(q, \tau, k) \tag{2}$$

where: $T(x)$ – temperature at point x, °C; q – the radiation power density, W/m²; k – thermal conductivity of latex W/m²·K; τ – the duration of the radiation pulse, s (Margelevičius, Vaitasius & Sajek, 2012).

Test objects are used to evaluate the reproduction of dashed details in a production environment. It should be noted that there is a variety of test objects and approaches to a set of fragments of the same type that are typical for each manufacturer. Evaluation of the performance of printing plates using these test objects does not give a complete picture of the quality of reproduction of image details of various sizes, and this is important and extremely necessary for the choice of printing plates when solving specific problems, regardless of the type of used platemaking device. Therefore, a universal characteristic is required that determines the reproduction of details of small sizes. This characteristic can be the modulation transfer function- MTF. It characterizes the dependence of the reproduced signal on its frequency and contains the characteristics of the reproduction of details of various sizes (Sajek, Kartasheva & Andreev, 2017).

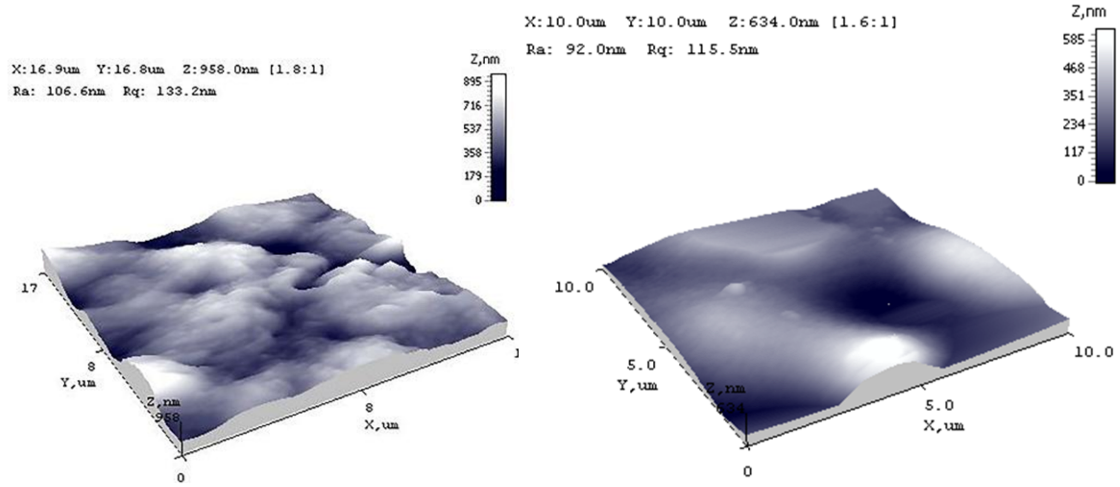
Results

Results of the study of the physical properties and integral quality indicators of offset termosensitive printing plates

To assess the surface morphology of the aluminum substrate and the parameters of the surface morphology of polymer layers, samples of two types of thermosensitive printing plates – Agfa Azura (negative) and Agfa EEP (positive) – were studied (Figure 2). For the aim to compare different offset printing plates in general, Fuji VPS-E (photosensitive positive) and Huaguang YP-Q (positive plate with copy layer) were also evaluated. During recording, the polymer layer of the Agfa Azura negative plate was irradiated in the areas of the printing elements. The polymer layers of the remaining three positive plates were irradiated in the areas of the non-printing elements, and the printing elements (non-irradiated areas) remained in their original state. So, the surface areas of the unexposed polymer coating were evaluated on these printing forms. The measurement results are shown in Table 1.

Table 1
The main indicators of the surface morphology of the studied plates

Number	Plate	R_a, nm of polymer	R_q nm of polymer	R_{max}, nm of polymer	R_a, nm of aluminum	R_q nm of aluminum
1	Agfa EEP	92	115	150	200	300
2	Agfa Azura	106	133	324	200	200
3	Fuji VPS-E	34,1	42,9	75	100	200
4	Huaguang YP-Q	40,7	54,4	80	200	300



» **Figure 2:** *Three-dimensional models of the layer's surfaces of the plates in the zones of printed elements: 1 – laser-exposed layer of Agfa Azura latex; 2 – unexposed thermopolymer Agfa EEP*

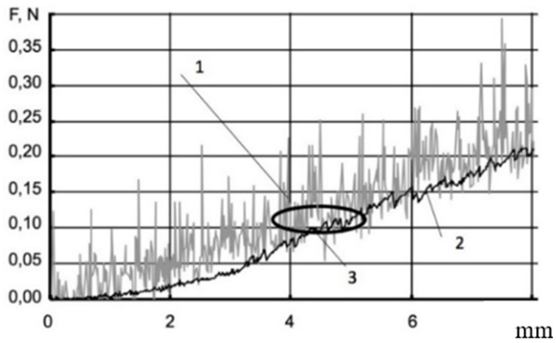
The results of studies of the **adhesion force of the surface** of the printing elements of the samples of printing plates Agfa EEP, Fuji VPS-E and YP-Q applying atomic force microscopy, are shown in Table 2.

Table 2

The magnitude of the adhesion force of the polymer layers surface of printing plates

Number	Plate	Adhesion force, nN
1	Agfa Energy Elite Pro	78,93
2	Fuji VPS-E	69,49
3	Huaguang YP-Q	51,05

Evaluation of the **adhesion force of the latex layer to the aluminum substrate** of the plate was carried out on Agfa Azura printing plates by scribing with a variable indenter load (Figure 3).



» **Figure 3:** *Distribution of normal F_N and tangential F_T scribing forces of the latex layer molten by laser action (q_0 = 100 mW): 1 – F_N, 2 – F_T, 3 – coating peeling zone*

The adhesion of the latex layer to the substrate surface changes after exposure to radiation, depending on the degree of melting of the layer. As can be seen from formula (1), the value of the temperature *T* of the latex layer when exposed to it by laser radiation is directly dependent on the power density of the laser radiation q_0, the pulse duration τ, as well as in inverse dependence on the characteristics of the material. In Figure 3 shows the distribution of normal F_N and tangential F_T scribing forces for the molten latex layer. It is obvious that the adhesion of the polymer layers of negative printing plates depends on the parameters of laser radiation, as well as on the physical and structural characteristics of the material (Margelevičius & Sajek, 2010; Sajek & Kartasheva, 2017).

Calculations of the relative adhesion force have shown that the relative adhesion of latex to the substrate depends on the type of radiation source. The value of the relative adhesion F_A of the latex layer melted by IR radiation and heated by a heat source is different: the adhesion of the layer heated with a heat source is one and a half times higher than the adhesion of the layer heated by IR radiation. This result can be explained by the influence of the temperature gradient in the zone of separation of layers during coating processing (Sajek & Kartasheva, 2017).

As a result of the XPS study of the **chemical state** of the surface of polymer layers, the zones of the printing elements were evaluated after recording the printing plates of Agfa EEP, Fuji VPS and YP-Q. On the ESCALAB-250Xi spectrometer, survey spectra of the surfaces of the polymer recording layers of the studied printing plates were obtained (Sajek, 2018).

With similar values of the surface morphology of the polymer layers (Table 1), its effect on adhesion on the layer surface in contact with the printing ink should be the same. With different values of adhesion (Table 2), it can be influenced by the chemical composition of the polymer layer and the concentration of chemical elements (for example, Na and Si). According to the results of the analysis of the spectra of Na and Si and the calculation of their atomic concentration (Table 3), it can be seen that the concentration of Na is practically the same on the surface of both photosensitive printing plates. No Na was found on the polymer surface of the Agfa EEP Na thermosensitive printing plate. The relatively low Si concentration on the surface of the Fuji VPS printing plate contributes to the presence of more surface energy than, for example, on the surface of the YP-Q printing plate, which is confirmed by the measurement results.

The surface morphology of the Agfa EEP thermosensitive plate is more rough compared to Fuji VPS and YP-Q printing plates. This state of the surface structure leads to an increase in the adhesion of the printing elements, despite the higher concentration of Si on the surface of the polymer layer.

Table 3

Results of calculations of the atomic concentration of Na and Si (%) from the XPS spectra of the surface of polymer layers

Printing plate	Adhesion force, nN	Chemical element	Bond energy, eV	Atomic concentration, %
Agfa EEP	78,93	Na1s	-	-
		Si2p	101,51	1,3
Fuji VPS	69,49	Na1s	1071.57	0,2
		Si2p	101.44	0.6
Huaguang YP-Q	51,05	Na1s	1071.18	0.3
		Si2p	101.75	4.2

To study the influence of the type and parameters of the thermal effect on the structure of the latex surface, it was calculated the temperature on the plate surface for specific recording conditions using formula (1). The results of calculating the temperature on the plate surface for specific recording conditions showed that the temperature of the latex layer, which is affected by the radiation energy density, is different. It has been confirmed that the power of laser radiation has an effect on the adhesion of latex to the substrate and on the stability of the printing elements.

The distribution of thermal energy in the latex layer of Agfa Azura plates was described using a temperature gradient. The values of the change in size (δ) of the diameter of the discrete element were calculated for a variable power density of laser radiation *q*, layer thickness *h*, for a variable diameter of the laser spot (Table 4) (Margelevičius, Vaitasius & Sajek, 2012).

Calculations of the change in the size of discrete elements showed that the power density of laser radiation and the density of the specific thermal energy of latex melting have practically no effect on the change in the size of the discrete element. At the same time, the greater the thickness of the latex layer, the greater the change in the size of the discrete element. Consequently, during digital recording of discrete elements on a thermosensitive latex layer, the change in their sizes depends to a greater extent on the diameter of the laser spot. The calculation results confirmed that the temperature distribution along the normal T_N is more efficient than its tangential distribution T_T. The relatively high temperature on the surface of the aluminum substrate, distributed in its volume due to the higher thermal diffusivity of aluminum in comparison with latex, increases the adhesion of the latex to the surface of the substrate.

To determine the **integral quality indicators** (image gradation, graphic elements reproduction accuracy, sizes of minimally reproducible line elements, etc.), the influence of modes and parameters of element-by-element recording on the reproductive properties of systems was studied: the position of image strokes relative to the recording direction (line and frame scanning), their spatial frequency, the rotation speed of the drum of the recording device, the radiation power and the resolution of the recording. Experimental results of assessing the reproductive properties of thermosensitive positive and negative offset plates are described: reproduction of line image details using the example of Fuji LH-PCE Brillia and Fuji LH-PJE plates, recorded on Creo Trendsetter 800 Quantum and CreoLotem 800 devices (Sajek & Valčiukas, 2021), respectively; gradation transmission of a raster image using the example of plate Agfa EEP, which was recorded on Screen Plate Rite 4300S (Sajek, 2014) and Agfa Azura, recordered on Heidelberg Suprasetter A74 devices. To assess the line details of the image, an original digital test object with lines from 10 to 150 µm wide was used (Sajek & Valčiukas, 2011).

As a result of the experimental data of reproduction of line details of the image and mathematical calculations, the MTF system of the “platemaking device-plate” was obtained for the Creo Lotem 800 device and Fuji LH-PJE thermosensitive plates and for the Creo Trendsetter 800 Quantum device and Fuji LH-PCE thermosensitive plates (Arutyunova, Kartasheva & Sajek, 2009; Sajek & Valčiukas, 2011). To assess the reproductive-graphic properties of the platemaking system, in which there is a certain blurring, the method of experimental evaluation based on the FPM was used, the parameters of reproduction quality of printing elements with different spatial frequencies and blurring in digital recording systems were determined. The research results showed that small strokes (10-15 microns wide, spatial frequency ν above 30 mm^{-1}), oriented perpendicular to the recording direction (frame scan), are better reproduced on these plates. Larger strokes (100 µm wide, spatial frequency ν- 5 mm^{-1}) are better reproduced in the recording direction (line scan) (Sajek, Kartasheva & Andreev, 2017; Arutyunova, Kartasheva & Sajek, 2009; Sajek & Valčiukas, 2021).

Conclusions

The article presents an original conceptual model for determining integral indicators of the quality of printing plates, taking into account their structural and physical properties; also selected methods for assessing the quality of offset thermosensitive printing plates based on the study of the influence of the structural and physical properties of their structural layers, as well as the parameters of digital recording on the quality of formation and reproduction of image elements.

Table 4

The values of the change in the size δ of a discrete element with a variable diameter of the laser spot

Diameter of the laser spot, $2r_o$, m	5×10^{-6}	10×10^{-6}	15×10^{-6}	20×10^{-6}
Latex layer thickness h =1.0 µm, power density q = 10^{11} W/m² · s (T = 185°C)				
Specific density of thermal energy, q_1, J/m²	$0{,}86\times10^{8}$	$0{,}43\times10^{8}$	$0{,}29\times10^{8}$	$0{,}22\times10^{8}$
Change in the size, δ, m	$0{,}22\times10^{-6}$	$0{,}44\times10^{-6}$	$0{,}65\times10^{-6}$	$0{,}85\times10^{-6}$
Latex layer thickness h=0/5 µm, power density q=10^{11} W/m² · s (T=185°C)				
Specific density of thermal energy, q_1, J/m²	$1{,}3\times10^{8}$	$1{,}5\times10^{8}$	$1{,}8\times10^{8}$	$2{,}0\times10^{8}$
Change in the size, δ, m	$0{,}11\times10^{-6}$	$0{,}22\times10^{-6}$	$0{,}33\times10^{-6}$	$0{,}43\times10^{-6}$

Within the framework of the research, the results of indicators of the surface morphology of the polymer layers and the substrate were obtained; adhesion of polymer layers of offset printing plates to the substrate surface, taking into account the influence of image recording parameters; the influence of the chemical state of the registering layers of offset plates on the adhesion of printing elements to inks was evaluated; the influence of the processes of thermal action of laser radiation and the temperature gradient on the surface structure of the polymer layer of a thermosensitive plate and the accuracy of the formation of discrete image elements on printing plates has been evaluated. The research results confirm the relationship between the structural and physicochemical properties of offset thermosensitive plates and integral indicators of the quality of image reproduction in a digital recording system.

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