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RESEARCH OF THE PRINTING PROPERTIES OF FORMALDEHYDE FREE BANKNOTE PAPER

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Дана тема є надзвичайно актуальною, так як папір є одним з основних витратних матеріалів для друку продукції. Характеристики банкнотного паперу повинні забезпечити стабільність відтворення друкованого зображення. В той же час потрібно зменшити вартість його виготовлення за умови збереження друкарсько-технічних показників на відповідному рівні, котрі забезпечать якість банкнот. На сьогоднішній день для друку банкнот використовується папір на меламінформальдегідній основі, проте його виготовлення є дорожчим, а випари формальдегіду є небезпечними для здоров'я обслуговуючого персоналу. Дослідження безформальдегідних зразків паперу також пов'язане зі змінами в світових тенденціях стосовно використання безформальдегідних проклейок. Задачі дослідження: аналіз та порівняння друкарсько-технічних характеристик банкнотного паперу на безформальдегідній основі та паперу на меламінформальдегідній основі. Наукова новизна дослідження полягає в визначенні відмінності між лінійною деформацією паперів з безформальдегідною проклейкою і тиражним папером (з меламінформальдегідною проклейкою).

Данная тема является чрезвычайно актуальной, так как бумага является одним из основных расходных материалов для печати продукции. Характеристики банкнотной бумаги должны обеспечить стабильность воспроизведения печатного изображения. В то же время нужно уменьшить стоимость его изготовления при условии сохранения печатно-технических показателей на соответствующем уровне, которые обеспечат качество банкнот. На сегодняшний день для печати банкнот используется бумага на меламиноформальдегидной основе, однако ее изготовления более дорогое, а испарения формальдегида являются опасными для здоровья обслуживающего персонала. Исследование безформальдегидных образцов бумаги также связано с изменениями в мировых тенденциях относительно использования безформальдегидных проклеек. Задачи исследования: анализ и сравнение печатно-технических характеристик банкнотной бумаги на безформальдегидной основе и бумаги с меламиноформальдегидной

основой. Научная новизна исследования заключается в определении отличий между линейной деформацией бумаг с безформальдегидной проклейкой и тиражной бумагой (с меламиноформальдегидной проклейкой).

Problem statement

Paper is one of the basic consumable materials which are used for printing products. Properties of banknotes paper should provide stability of reproduction of the printed image. Besides, banknote paper properties are an extremely important factor in ensuring durability of banknote printing products. In terms of durability high degree of sizing would be the most desirable, what would provide a non-porous surface of the substrate, but, another important requirement for paper is the necessity of ink penetration into the paper for its fixing to sheet. That's why the degree and method of sizing are chosen optimally by two opposing factors - adhesion of inks and soiling resistance [1]. At the same time the cost of the paper manufacturing must be reduced providing preservation of printing properties at the appropriate level, which will ensure the quality of the banknotes.

Nowadays, for banknotes printing process the paper on melamine-formaldehyde basis is used. However, formaldehyde belongs to the third class of hazardous substances, is a strong allergen and a carcinogen, and causes irritation of the skin and mucous membranes. Evaporation of formaldehyde is hazardous both for health of manufacture employees and, according to the latest data, for users of products, which contain formaldehyde [2].

So the latest global trends are use of formaldehyde free sizing of paper, particularly for the banknotes production [3] using sizing on basis of polyamide-epichlorohydrin resins [4].

Having undeniable advantages over formaldehyde sizing concerning environmental production and non-toxic for users, formaldehyde free types of paper may have the worse printing properties and resistance to deterioration [4], so the use of such types of paper in the banknotes production requires further researching.

Purpose

Purpose is a research and comparison of printing properties of banknote paper with formaldehyde free sizing and paper with melamine-formaldehyde sizing.

Research results

The samples of four types of banknote paper were used in the research:

— Single-layer tirage paper with melamine-formaldehyde sizing;

— Double-layer experimental paper of three types (with melamine-formaldehyde and formaldehyde free sizing).

To start prototypes comparison the input control of banknote paper was carried out according to the documentation requirements. Properties of all types of paper are given in Table 1.

Table 1

The properties of banknote papers

Pos. №	Indicator name	Tirage	Experimental 1	Experimental 2	Experimental 3
1	Number of layers	Single-layer	Double-layer	Double-layer	Double-layer
2	Sizing	MF*	MF	FF**	FF
3	Grammage, g/m^2	87.0	82.7	82.8	91.4
4	Thickness (outside the watermark), μm	109±3.0	108±2	109±2	123±2
5	Excess paper thickness on watermark, μm	–	12	11	8
6	Bursting strength, N: — in machine direction — in cross-machine direction	 113 61	 125 65	 112 58	 120 63
7	Tensile elongation, % — in machine direction: — in cross-machine direction	 5.0 	 5.6 10.6	 5.8 10.6	 5.6 9.9
8	Folding endurance: — in machine direction — in cross-machine direction	 5422 3421	 5538 6375	 5402 2881	 5431 3395
9	Water absorptivness, g/m^2 (Cobb$_{60}$): — top side of paper — wire side paper	 31.5±2.0 30.5±3.0	 27.0±3.0 42.0±3.0	 31.0±4.5 34.5±5.0	 36.5±2.0 38.0±3.0
10	Wet strength (machine direction), %	46.7	44.2	43.4	45.9
11	Opacity, %	90.0	88.5	91.5	92.5
12	Roughness, cm^3/min top side / wire side	377/384	447/431	316/327	367/321
13	Surface strength	18	18	18	18
14	Linear elongation (cross-machine direction), %	2.0	1.8	1.9	1.9
15	Tearing resistance (machine direction), mN	870	840	710	925
16	Ash content, %	2.4	2.1	2.7	2.6
17	pH water extract	6.6	6.9	7.7	7.4
18	Moisture content, %	6.8	7.1	6.8	6.6

* MF — melamine-formaldehyde sizing, FF** — formaldehyde free sizing.

Analysis of the paper properties shows that the formaldehyde free types of paper (Experimental paper 2, Experimental paper 3) have a slightly worse indices of folding endurance, wet absorptiveness, bursting strength, compared with a double-layer paper with melamine-formaldehyde sizing (Experimental paper 1), however, the properties of formaldehyde free double-layer paper is slightly different from the tirage paper, which is single-layer with melamine-formaldehyde sizing.

After the quality measuring paper sheets were printed by offset printing method on machine Super-Simultan 312 by tirage inks at a speed of 8.5 thousand sheets per hour under climate conditions in the pressroom: the temperature: 21.7±0.1 ˚C, relative humidity: 50±2.0 %. During the printing process selective quality control of offset products was carried out. For a more objective comparative evaluation pile was formed, which contained 100 sheets of each type of research paper and 100 sheets of tirage paper.

Ink-perception estimation for all types of paper was made by means of measuring the optical density of offset inks on sheets — semi-finished products. Measurements were carried out on the front and back side of sheets on Autosmart (ColorChek) integrated into the machine Super-Simultan 312. The results of optical density measurement for different offset inks are given in Table 2, 3. These data show that the tirage and experimental papers have almost the same value of the optical density of sheets, as well as the deviation of optical density for each ink.

Besides, it was found that drying time of offset semi-finished products was 7 days on formaldehyde free types of paper, while this index was 16 days for types of paper with melamine-formaldehyde sizing.

At the next stage, offset semi-finished products were printed by intaglio printing (steel engraving) on machine Super-Orloff-Intaglio.

Table 2

Offset inks optical density on sheets (front side) for experimental and tirage types of paper

Banknote paper types	Ink						
	red	light-brown	brown	azure	violet-pink	violet	dark-red
Tirage	0.34 ±0.01	0.56 ±0.01	0.70 ±0.02	0.61 ±0.01	0.49 ±0.01	0.60 ±0.01	0.92 ±0.01
Experimental 1	0.35 ±0.01	0.58 ±0.02	0.72 ±0.03	0.62 ±0.01	0.53 ±0.02	0.61 ±0.01	0.93 ±0.01
Experimental 2	0.34 ±0.01	0.56 ±0.01	0.69 ±0.02	0.61 ±0.01	0.50 ±0.01	0.60 ±0.01	0.92 ±0.02
Experimental 3	0.34 ±0.01	0.56 ±0.01	0.68 ±0.02	0.62 ±0.01	0.50 ±0.01	0.60 ±0.01	0.92 ±0.02

Table 3

Offset inks optical density on sheets (back side) for experimental and tirage types of paper

Banknote paper types	Ink									
	red	light-brown	brown	azure	violet-pink	violet	grayish-pink	pink	dark-red	violet-black
Tirage	0.35 ± 0.01	0.27 ±0.01	0.52 ±0.01	0.27 ±0.01	0.47 ±0.01	0.33 ±0.01	0.39 ±0.02	0.54 ±0.01	0.97 ±0.01	0.99 ±0.02
Experimental 1	0.36 ±0.01	0.29 ±0.01	0.53 ±0.01	0.28 ±0.01	0.48 ±0.01	0.34 ±0.02	0.41 ±0.01	0.55 ± 0.01	0.99 ±0.01	0.99 ±0.01
Experimental 2	0.35 ±0.01	0.26 ±0.01	0.51 ±0.01	0.27 ±0.01	0.47 ±0.01	0.33 ± 0.01	0.39 ±0.02	0.54 ±0.01	0.96 ±0.01	0.98 ±0.01
Experimental 3	0.35 ±0.02	0.26 ±0.01	0.51 ±0.01	0.26 ±0.01	0.47 ± 0.01	0.33 ±0.01	0.39 ±0.01	0.54 ±0.01	0.98 ±0.01	0.99 ±0.01

One of the features of intaglio printing is the usage of viscous paste inks on the basis of the organic solvent–wax. Owing to heat of plate cylinder of presses (printing machines) of intaglio printing to 80–82 °C ink (or rather, wax compound) is being melted, that changes its rheological properties (decreasing viscosity and increasing flow ability), increasing the adhesion and penetration into the structure of the paper substrate. Moreover, the ink is transmitted at high pressure — linear pressure between the plate cylinder and print cylinder during the intaglio printing process is up to 1000 kN/m [5]. All mentioned causes the deformation of sheets during the printing process. So after intaglio printing offset image was measured again to determine possible linear deformation during intaglio printing process.

For measurement nine sheets of each paper type were chosen. Measurements were carried out by a special ruler Herlinger with precision measuring 10^{-1} mm. After obtaining data on deformation indices for nine sheets arithmetic mean $\bar{x}$ was calculated using the formula (1). Deformation indices are given in Table 4.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \qquad (1)$$

where x_i — date of i-th measurement; n — measurement number.

The data in Table 4 allow us to make conclusion, that all researched types of paper have deformation of offset image after intaglio printing. However, types of paper with formaldehyde free sizing have the smallest total deformation.

The data on size of intaglio image for researched types of paper are given in Table 5. Drying time of intaglio printing inks was the same for all types of paper (72 hours).

The data in Table 4 and 5 allow us to make conclusion that as offset so intaglio images have minor deviations which don’t exceed requirements indicators [6].

Table 4

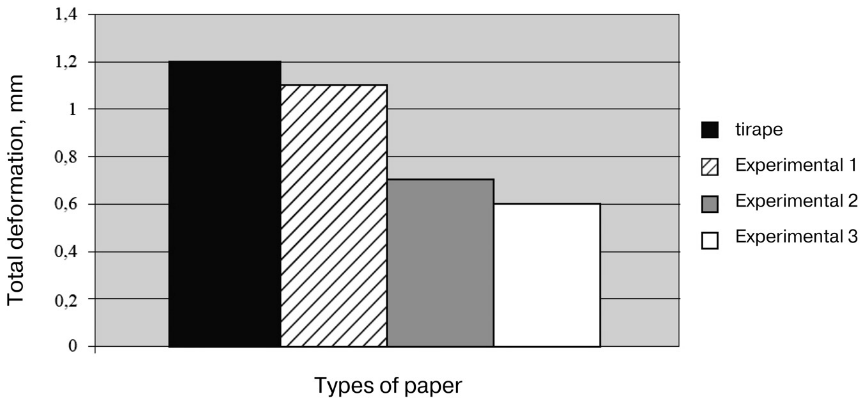
Offset image linear deformation during intaglio printing process

Paper types	Offset image size, mm								Offset image deformation, mm				
	Before intaglio printing				After intaglio printing								
	Flap	Automate	Tail	Anti-Automate	Flap	Automate	Tail	Anti-Automate	Flap	Automate	Tail	Anti-Automate	Total (modulo)
Tirage	568.0	525.2	567.2	525.1	568.2	525.2	568.1	525.0	0.2	0.0	0.9	-0.1	1.2
Experimental 1	567.9	525.2	567.2	525.1	568.1	525.0	567.9	525.1	0.2	-0.2	0.7	0.0	1.1
Experimental 2	567.9	525.1	567.1	525.0	567.8	525.1	567.7	525.0	-0.1	0.0	0.6	0.0	0.7
Experimental 3	567.8	525.1	567.1	525.0	567.8	525.1	567.6	525.1	0.0	0.0	0.5	0.1	0.6

Table 5

Intaglio image size for different types of paper

Banknote paper types	Intaglio image size, mm			
	Flap	Automate	Tail	Anti-Automate
Tirage	568.1	524.9	567.9	524.6
Experimental 1	567.9	525.0	567.9	524.7
Experimental 2	568.0	524.9	567.9	524.7
Experimental 3	568.1	524.9	568.0	524.6



The total deformation of offset image during intaglioprinting (in absolute value) for different types of paper

Next stage of technological process is numbering on machine Super-Numerota III with UV fixing. Selective quality control of printed sheets carried out during printing process didn't detect significant defects of image. It was also found, that drying time for numbering printing inks was identical for all types of the paper — 72 hours.

Conclusions

Analysis of all researched types of paper properties showed that the formaldehyde free types of paper have a slightly worse indices of folding endurance, wet absorptiveness, bursting strength, compared with a double-layer paper with melamine-formaldehyde sizing, but the properties of formaldehyde free double-layer paper is slightly different from the tirage paper, which is single-layer with melamine-formaldehyde sizing. Thus, the production of double-layer paper with formaldehyde free sizing allows getting the paper possessing properties not worse than tirage paper.

The tests for compliance with standards of printing properties for formaldehyde free banknote paper and banknote paper with melamine-formaldehyde sizing were carried out.

Optical density of offset image and linear deformation of offset printing image during intaglio printing process were measured.

Ink-perception of offset printing inks assessed by means of their optical density deviation on sheets of experimental and tirage types of paper was in permissible limits.

Drying time for offset semi-finished products on formaldehyde free types of paper more than twice less than for tirage paper: for formaldehyde free types of paper it is 7 days, while for paper with melamine-formaldehyde sizing — 16 days.

Drying time for intaglio and numbering printing inks are the same both for experimental and for tirage paper (72 hours).

The results of the linear deformation tests for offset image on sheets after intaglio printing showed that all researched types of paper have offset image deformation after intaglio printing. However, the paper with formaldehyde free sizing demonstrated the smallest total deformation.

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