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STUDY OF THE QUALITY OF PRINTED IMAGES ON CARDBOARD PACKAGING

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The intensive development of the packaging industry puts forward increased requirements for the design of packaging, the quality of their decoration with printing technologies. There are increased requirements for packaging materials, in particular their environmental friendliness. Therefore, many manufacturers prefer a material such as cardboard, which is completely recyclable. The article is devoted to the study of the gravure printing quality on cardboard imprints. An analysis of influencing factors on the quality of densitometric and colorimetric indicators of imprints is carried out. The surface structure of imprints is studied. On the basis of experimental studies, diagrams of the optical density of printed images on cardboard with different grammage and structure are constructed. Colorimetric studies of imprints are presented. The influence of the cardboard structure and roughness on the quality indicators of gravure imprints are confirmed.

Keywords: *cardboard, imprints, structure, gravure printing, optical density, color reproduction, quality.*

Problem statement. The development of the packaging industry has become a priority sector of the economic development of many countries of the world in recent decades. It is one of the ten largest industrial sectors of each country. The entire global packaging market is currently valued at more than US$ 500 billion. The dominant technologies of printing on cardboard packaging remain the classic methods – offset, flexographic, gravure printing. Gravure printing, despite its high quality, a few years ago was considered conservative, not very innovative and less profitable compared to flexography. Recently, this opinion about gravure printing has changed thanks to a number of technological innovations. Recently developed processes of automation of prepress preparation, as well as a faster and better-quality process of manufacturing printing forms by laser engraving and a shorter preparation time of a gravure printing machine have significantly increased its productivity and economic efficiency [1]. In Europe, gravure printing and flexography occupy approximately equal market share in this important segment, but gravure printing plays a leading role in the dynamically developing packaging market. In the developing countries of Asia, gravure printing has 80%, and flexography – 20% of the market [2]. This is especially true in China and India with their fast-growing markets and over 1 billion consumers in these countries. The most important characteristics of gravure printing (for example, excellent imprints quality in large runs) naturally create favourable conditions for the position of gravure printing in these markets.

However, according to an analysis by Future Market Insights, in 2022 the revenue of the gravure printing market is estimated to be US$ 1.9 billion. Despite the challenges of recent years, with demand driven by various industries recovering from the pandemic, the global mechanical engineering market is forecast to reach US$2.7 billion by 2032, accelerating at a CAGR of 3.5% over the forecast period [3,4]. Gravure printing has its advantages and disadvantages. The positive sides are the long service life of the printing cylinder (more than 1 million copies), variability of printing formats, printing of the front side of the paper and the back side in one pass, different primary colours and printing materials, high quality, simple printing. The main disadvantages are the expensive cylindrical engraving process [5], the long, labour-intensive preparation, and the high failure rates of 3% or more (for large runs) that can occur during setup and starting a new project. This is a high-cost factor, especially for relatively short series [6]. Due to the high speed of gravure printing machines, ink transfer takes 1-3 milliseconds. In this short time, the ink should be evenly transferred from the small cells to the surface of the substrate. Ink transfer is often assisted by electrostatic assistance (ESA), which creates an electrostatic field on the contact surface [12]. The electrostatic field lifts the ink from the cells and improves the contact between the printing ink and the substrate. When using the ESA system, the degree of depletion of the printing elements can be 80-95%, and without support the efficiency is about 50-65% [9]. Unfortunately, despite the numerous advantages of cardboard packaging, not all goods can be packed in it. This applies in particular to the food industry, where loose, dry, wet and fatty products can mostly only be packaged using foil or laminate. By using the appropriate raw materials, you can guarantee a barrier to water vapor, oxygen, aromas, which provides optimal product protection and extends the shelf life of packaged food.

Therefore, gravure printing on cardboard packaging attracts the attention of researchers, in particular, the identification of factors affecting the quality of printed images on cardboard packaging.

Analysis of recent research and publications. Quality control of gravure printing of packaging is critical due to several factors. First of all, the quality of printing directly affects the image of the brand and the perception of the product by consumers. In addition, there is no room for error in the case of high volumes and high production costs of rotogravure packaging. Any error can lead to additional costs and delays in production, which can have a negative impact on production schedules and efficiency. Printing quality control allows errors to be detected and corrected before the product is released to market, minimizing the risk of costly errors, delays or complaints. Although gravure printing on cardboard packaging has been used for a long time, the emergence of new materials, printing inks, and increased consumer demands prompts product manufacturers to continue intensive research into the factors influencing the quality of imprints. Thus, in the work [3], the authors present the results of the study of the mechanism of image formation by gravure printing. Some authors devote their research to the influence of the structure of the form cylinder, anilox roller, the angle of inclination of raster cells, their capacity and shape on the quality of imprints [4,6]. Currently, gravure roll machines in various configurations are popular. The pressure cylinder (press) is covered with a layer of rubber of the appropriate hardness. Since the press has a smaller diameter than the form cylinder, it can be deformed. To prevent this, it is pressed with one or two metal rollers. Ink can also be applied to the form cylinder in a variety of ways. However, the constant principle is that excess ink is removed with a sharp metal knife (blade) placed immediately in front of the print area to reduce the amount of solvent that evaporates from the ink. The blade setting has a significant impact on printing quality. Its variable parameters are the installation angle, the pressure on the form, the size and frequency of the axial movement, and the width of its edge in the contact area. Inks for gravure printing are liquid with a viscosity of 50 - 250 mPa•s [5]. Depending on the type of substrate and cylinder, the ink should be diluted to the desired viscosity (for example, for a paper substrate it is about 15 mPa•s). Inks for gravure printing must meet several requirements. They must precisely fill the printing elements of the gravure cylinder, but at the same time must be easily removed with a blade from non-printed surfaces and easily transferred to the printed substrate. The amount of ink transferred to the substrate depends on the depth of the printing elements. It can be assumed that this depth is (for all types of substrates) on average about 25 μm. If we assume that only 50% of the ink is transferred to the substrate, then we get 12.5 μm [6]. Inks for gravure printing on packages are divided into two main groups: solvent-based and water-based. In the case of solvent-based inks, binder mixtures with a predominance of nitrocellulose (NC) are most often used, and their solvent is usually isopropyl acetate. Other resins are also added to the binder. These inks have a low inherent odour (for printing food packaging) and are designed for printing paper products, aluminium foil and metallized paper. With multi-colour gravure printing, drying must be carried out after each printing section [10-11]. The solvent evaporates from the ink due to the presence of hot air, but some of it is absorbed by the porous substrate. If the ink dries too quickly, it means that its viscosity increases significantly, which can lead to heat generation and transfer problems to the substrate. Therefore, further cooling of the ink fountain is necessary. The high temperature of the drying chamber also accelerates the drying process itself, but there is a limit beyond which the substrate curls, causing problems with printability and the printing process [12].

Automation of quality control of imprints is considered in the article [6]. The problem of the general process of quality control of packaging in the context of their environmental friendliness and safety, printing design, is considered on the example of a cardboard box for a pharmacy using the Pareto diagram [7,8]. However, the factors ensuring the quality of imprints, taking into account the structure of the cardboard surface, in particular roughness, are not yet sufficiently studied.

The aim of the research. The purpose of the work was to study the densitometric and colorimetric indicators of the quality of gravure printed images on cardboards of different grammage and structure.

Presentation of the main research material. The objects of research were cardboards with different grammage and structure. SBS cardboard has high whiteness, stiffness and mechanical strength, consists of a two-layer coating on both sides. Incada Silk and Koppargloss cardboards are made from primary fibres and consist of outer bleached layers of chemical cellulose, inner layer of mechanical cellulose. The characteristics of cardboard are given in table 1.

Table 1

Characteristic of cardboards

Cardboards	SBS Ensocoat L	FBB Koppargloss	FBB Incada Silk C
Grammage [g/m2]	240	200	220
Thickness [μm]	255	330	350
Humidity [%]	6.5	7,0	6,5
Whiteness [%]	95,0	91,2	91,5
Brightness 75° [%]	48	50	50
Roughness PPS10 [μm]	1,0	0,9	0,8
Roughness Taber 15° CD [mNm]	5,1	4,9	4,8
Roughness Taber 15° MD [mNm]	11.1	12,0	9,9

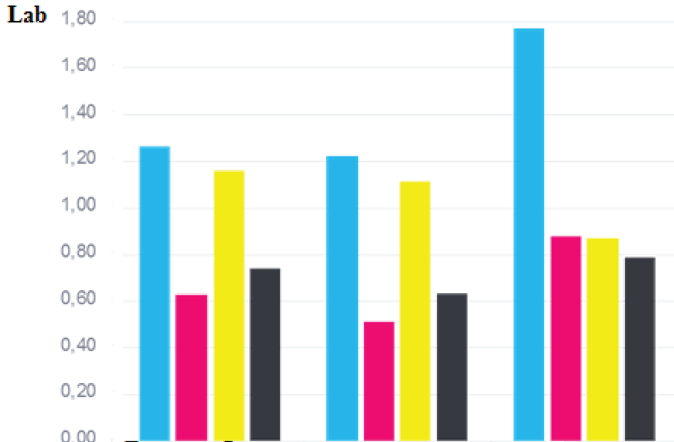
The packaging was printed with solvent inks that contained ethyl acetate, ethanol, and isopropyl acetate, as well as smaller amounts of isopropanol and 1-ethoxy-2-propanol in various configurations, depending on the type of ink used. Magenta, Cyan, Yellow ink viscosity -18 [mPa•s], drying temperature -30°C. The imprints were printed on a BOBST Lemanic Riviera 820 machine.

An X-Rite 500 series spectrophotometer was used to measure the colour difference and optical density of imprints. The color measurement was done taking specular reflection into account, and the observation conditions were at an angle of 2º (CIE 1931) with standard luminant D50 (daylight, colour temperature: 5003 K).

For each test, the samples were conditioned without access to light, so that temperature, humidity and sunlight do not affect the determination of quality parameters. The instability of these factors can cause irreversible changes in the cardboard structure and affect the unevenness of the final results. Therefore, before testing the substrate and packaging samples, they were conditioned at a temperature of 23±1°C and a relative humidity of 50±2% without access to sunlight.

To study the structure of the surface of cardboard and imprints on them, an AniCam measuring device from TROIKA Systems Limited was used, which is equipped with a 24-bit colour camera with a resolution of 640×480 pixels and a field of view from 1.25×0.92 mm.

The results of studies of colour saturation on imprints showed (Fig. 1) that the largest Lab for Cyan colour was achieved on imprints on Incada Silk C cardboard – (1.77), smaller on Ensocoat L cardboard (1.27), the smallest on Koppargloss cardboard (1.22). A similar pattern was observed on the imprints for the Magenta and Black colour difference. The reverse pattern is typical for Yellow ink - the maximum colour difference is typical for imprints on Ensocoat L cardboard (1.16), slightly smaller (1.11) for imprints on Koppargloss cardboard and the smallest on Incada Silk C cardboard (0.87).



	Ensocoat L	Koppargloss	Incada Silk C
Cyjan	1,27	1,22	1,77
Magenta	0,63	0,51	0,88
Yellow	1,16	1,11	0,87
Black	0,74	0,63	0,79

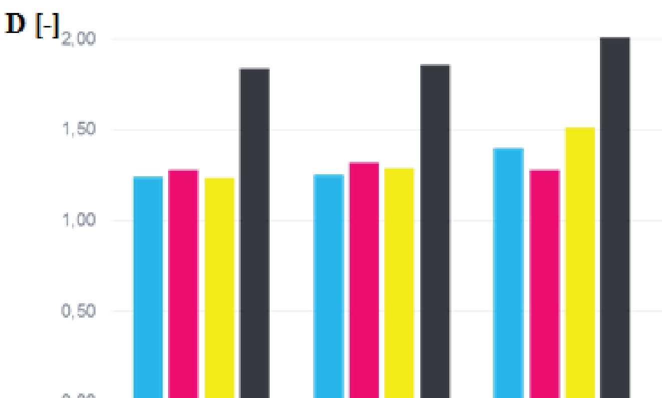
Fig. 1. Colour difference diagrams on cardboard imprints

Figure 2 shows diagrams of optical density of printed images on imprints. As can be seen, by increasing the value of the optical density for Black ink, imprints can be placed in a row:

Koppargloss < Ensocoat L < Incada Silk C

1,84 < 1,86 < 2,01

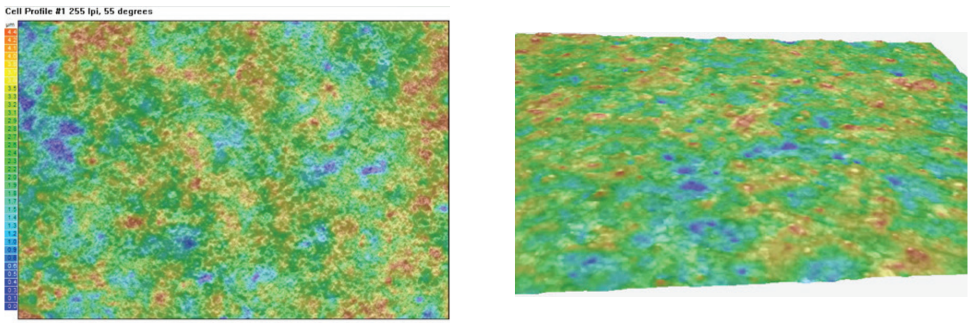
A similar picture is observed for Yellow and Cyan ink. The picture is slightly different for Magenta imprints: the maximum optical density is 1.32 on Koppargloss cardboard, slightly smaller values (1.28) have imprints on Ensocoat L and Incada Silk C cardboards.



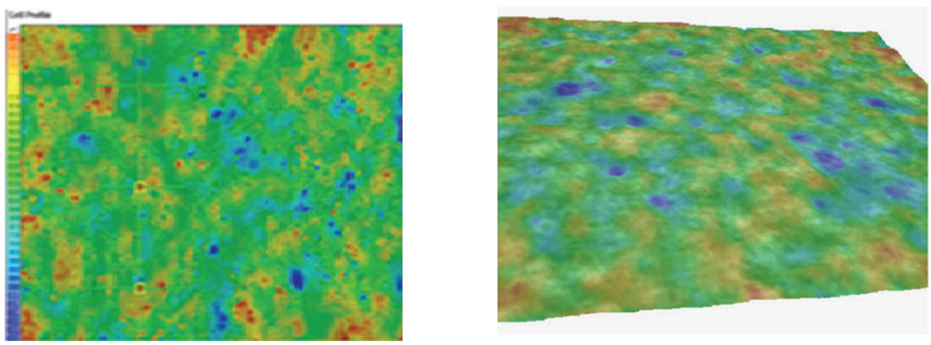
	Ensocoat L	Koppargloss	Incada Silk C
Cyjan	1,24	1,25	1,40
Magenta	1,28	1,32	1,28
Yellow	1,24	1,29	1,52
Black	1,84	1,86	2,01

Fig. 2. Diagrams of optical densities of printed images

As can be seen, imprints on Incada Silk C cardboard, which has a smoother surface (roughness PPS10 -0.8 μm) compared to others, have the highest value of optical density of printed images. Their surface structure contributes to the uniform application of ink and the same reflection of light, which leads to an increase in optical density.



a



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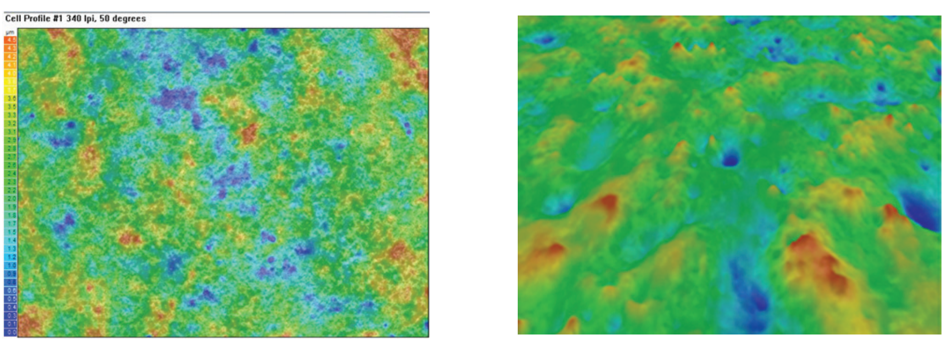

c

Fig. 3. Topography of the surface structure of imprints and their 3D models on cardboard: Koppargloss (a); Incada Silk C (b); Ensocoat L(c)

As a result of studies of imprints structure (Fig. 3), the significant influence of the characteristics of the surface of the cardboard on the process of ink absorption during printing was confirmed. Research has established that the roughness parameter of cardboard affects the quality of imprints. Smoothness (roughness) characterizes the microstructure of the cardboard surface and uniformity, which determines its volumetric macrohomogeneity and affects the efficiency of interaction with ink. Studies have shown that coating has an effect on roughness. A uniform distribution of structural elements is observed in the studied cardboard Koppargloss and Incada Silk C. The absence of large macro irregularities is due to the presence of two coating layers on the surface of the cardboard. Analysis of cardboard surface profiles and microphotographs of the structure shows that the presence of a double coating reduces the roughness parameter.

The studied cardboards with a double coating have an average degree of surface irregularities from -4.1 to +2.02 microns, there are no large macro-irregularities. The smooth surface of the coated cardboard contributes to the formation of a strong bond between the ink and the cellulose fibres, ensures its uniform distribution on the imprint and high quality of the printed image. Ensocoat L cardboard is characterized by a greater degree of surface irregularities, which is explained by the absence of a second coating layer. Micrographs of the 3D model of imprint show micro- valleys that remain unsmoothed after the ink layer is applied.

The presence of a coating on the cardboard contributes to the reduction of the roughness indicator, more uniform application of ink (regardless of color) to the imprint. The roughness parameter Ra=0.8 μm indicates a highly developed micro- and sub-microstructure of the surface and high-quality reproduction of images printed on Incada Silk C cardboard with a double coating layer. Ensocoat L cardboard with a single coating is characterized by a large degree of surface irregularities from –5.36 to +6.87 μm, an increase in the roughness parameter Ra=1.0 μm. The quality of printed images is much lower.

Conclusions. Thus, experimental studies of optical density, colour difference confirm that the quality of gravure imprints is affected by the topography of the substrate, the presence of the number of coating layers on the surface of the cardboard, its roughness (smoothness).

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ДОСЛІДЖЕННЯ ЯКОСТІ НАДРУКОВАНИХ ЗОБРАЖЕНЬ НА КАРТОННИХ ПАКОВАННЯХ

Єжи Чубак

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Інтенсивний розвиток пакувальної галузі висуває підвищені вимоги до конструкції паковань, якості їх оздоблення поліграфічними технологіями. У поле зору дослідників та виробників пакувальної продукції потрапляють експлуатаційні характеристики пакувальних матеріалів, зокрема їх екологічність, безпечність, дизайн конструкції, її міцність та витривалість тощо. Оскільки сучасні виробники паковань надають перевагу матеріалу, здатному до рециклінгу, об'єктом дослідження в цій статті були паковання, виготовленні з картону. Зокрема стаття присвячена дослідженню якості відбитків глибокого друку. Здійснено аналіз факторів впливу на денситометричні та колориметричні показники надрукованих зображень. Досліджено поверхневу структуру відбитків на картонах різної граматури та структурної будови. Аналіз топографії поверхневої структури відбитків та їх 3D-моделей підтвердив, що наявність крейдованого покриття на поверхні картону впливає на значення показників оптичної густини та різниці кольорів надрукованих зображень. На основі експериментальних досліджень побудовано діаграми оптичної густини відбитків. Виявлено, що для всіх кольорів CMYK, окрім magenta, значення оптичної густини найвищі для картонів з наявним подвійним крейдованим покриттям, які мають менший показник шорсткості (PPS10 -0,8 μm), рівномірнішу мікроструктуру поверхні, яка визначає його об'ємну макрооднорідність і впливає на ефективність взаємодії з фарбою. Досліджено колориметричні показники відбитків, за значеннями Lab побудовані діаграми, які показали вплив структурної будови субстратів на якість надрукованих зображень. Таким чином експериментальні дослідження денситометричних та колориметричних показників (оптичної густини, різниці кольорів) підтвердили, що якість відбитків глибокого друку залежить від топографії картонів, наявності на їх поверхні крейдованого покриття, шорсткості.

Ключові слова: *картон, відбитки, структура, глибокий друк, оптична густина, кольоровідтворення, якість.*

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