UDC 655. 3.022+676.2
DOI: 10.15587/1729-4061.2025.338268

RESEARCH OF THE PERFORMANCE INDICATORS OF PRINTING IMPRESSIONS ON CARDBOARD FOR PACKAGING PRODUCTION

Svitlana Havenko
Corresponding author
Doctor of Technical Sciences, Professor,
Head of Department*
E-mail: svitlana.f.havenko@lpnu.ua
Ivanna Koniukhova
PhD, Associate Professor*
*Department of Printing
Technologies and Packaging
Lviv Polytechnic National University
S. Bandery str., 12, Lviv, Ukraine, 79013

In modern packaging production, a diverse range of cardboards is used. Therefore, the current problem is the choice of cardboards to ensure the functional purpose of packaging. The object of the study was printing impressions for the production of cardboard packaging.

Methods for studying the operational properties of cardboards that arise during the use of packaging are proposed. Based on the conducted electron microscopic studies, the influence of the structural structure of cardboards on the mechanical and physicochemical properties of printing impressions has been confirmed. The presence of waste paper and mechanical pulp in the cardboard structure increases the water absorption rate of the printing impression. The value of the relative tensile deformation of cardboard in the transverse and longitudinal directions has been determined. It has been found that with an increase in the tensile value, the ability of packaging to compensate for mechanical loads without destruction increases. The maximum anisotropy coefficient and compression modulus of cardboard impressions have been calculated. When ensuring the safety of packaged products, problems arise related to the appearance of solvent migration from printed images on packages. Chromatographic studies have confirmed that with an increase in the number of coated layers on the surface of offset impressions, the migration of paint solvents to the contents of the packages decreases. This allows the selection of cardboard for the manufacture of packages taking into account their structural structure. The results obtained make it possible to improve the technological process of manufacturing cardboard packages, ensuring their environmental friendliness and consumer properties according to their functional purpose

Keywords: offset impressions, low-migration paints, deformation properties, cardboard structure, electron microscopy, packaging strength

Received 09.06.2025
Received in revised form 30.07.2025
Accepted 18.08.2025
Published 30.08.2025

How to Cite: *Havenko, S., Koniukhova, I. (2025). Research of the performance indicators of printing impressions on cardboard for packaging production. Eastern-European Journal of Enterprise Technologies, 4 (1 (136)), 55–66. https://doi.org/10.15587/1729-4061.2025.338268*

1. Introduction

Packaging production is one of the largest and most promising sectors of the economy of many countries around the world. The rapid dynamics of packaging needs is due to the growth of consumer goods production, the development of trade and logistics, as well as increasing requirements for the quality and safety of packaged products. The modern packaging industry is experiencing fundamental changes driven by two main factors: ecology and technology. Growing environmental awareness of consumers and stricter international regulatory standards make environmental friendliness the main driver of innovations in packaging production. The use of renewable materials, the introduction of innovative technologies aimed at reducing the environmental footprint and the transition to closed production cycles are becoming key trends in the production of cardboard packaging [1].

In packaging production, robotic systems and automated lines are increasingly used, which increase the efficiency of production processes and reduce the cost of products. In parallel, in the field of packaging design, there are trends towards minimalism and the use of storytelling elements as a means of enhancing communication with the consumer.

Digitalization is confidently entering the packaging industry. Smart packaging is becoming increasingly popular. The use of RFID tags, QR codes, NFC chips allows to track the product at all stages, provide consumers with additional information (about composition, origin, expiration date) and protect against counterfeiting.

Modern packaging is increasingly acquiring interactive properties thanks to the use of augmented reality (AR) technologies. Using mobile applications, the consumer can scan an image or QR code on the packaging and gain access to additional digital content – instructions, video materials, advertising campaigns or interactive games. This increases user engagement and creates new channels of communication between the manufacturer and the consumer. In parallel, 3D printing technologies are developing, which allow for the production of personalized packaging for individual orders, which helps to increase the competitiveness of products in the market.

An important stage in the development of the packaging industry is the Internet of Packaging (IoP), which creates interaction between packaging, packaged product and consumer. This connection can be made by scanning a unique identifier (QR code) at various stages of the logistics of the packaged product. Packaging is becoming an increasingly multifunctional, technological and ecological tool that plays a key role in modern business and consumption

Researchers predict that the future of the packaging industry will be shaped at the intersection of innovation, sustainability and personalization. According to Smithers Information experts, the volume of the global packaging market is approximately 1.015 billion dollars. Estimated annual growth rates during 2023–2026 for packaging material segments: cardboard: 5%, plastic: 4%, metal: 3% and glass: 2% [2].

According to Smithers Information experts, the global packaging market is projected to grow to 1.42 trillion USD by 2028. The compound annual growth rate (CAGR) for packaging will be 3.9% over the next five years [3].

The results of a survey of 1,025 consumers in the study [4] show that an important attribute of food packaging is the use of information on labels. After all, it informs the consumer about the quality of the products and plays an important role in making a purchase decision.

Sociological surveys [5] show that the vast majority of consumers prefer protective packaging (83.3%), but also pay attention to its environmental friendliness. 79.8 percent of consumers consider it important to have comprehensive information about the product that can be easily and conveniently read on the packaging. More than half (54%) of consumers aged 18 to 34 choose products with environmentally friendly packaging "always" or "often". 34 percent of consumers prefer environmentally friendly packaging even when it is less convenient than traditional packaging. 79% of respondents are willing to pay more for environmentally friendly packaging.

The increasing interest of consumers in safe and convenient packaging, in particular for food products and children's goods, stimulates the development of innovative safe materials. Government agencies, like consumers, are paying more and more attention to environmental protection and the environment. The demand for environmentally friendly packaging materials is growing. Further development of biomaterials from plant raw materials that are completely biodegradable is expected. New types of cardboard and corrugated cardboard with improved properties are being produced. All this minimizes the impact on the environment at all stages of the packaging life cycle. Cardboard packaging occupies a special place in the implementation of the "Zero Waste" concept, aimed at reducing the ecological footprint and preserving the planet's resources.

Thus, studies devoted to evaluating the performance indicators of printed impressions on cardboard are relevant, since they determine the barrier, mechanical and functional properties of packaging, which directly affect their quality, safety and environmental friendliness.

2. Literature review and problem statement

The importance of using new ecological systems in the development of packaging for food products is emphasized in the study [6]. Such technologies are a significant challenge for the industry, as they minimize the impact on the environment. However, plastic is still widely used for packaging food products. This is explained by its low cost, high barrier properties, tightness, resistance to mechanical damage, and convenience for the consumer. In addition, such packaging has the ability to be heated, reused, branded, and complies with sanitary and hygienic standards. It is important to note that the use of plastic has serious disadvantages, in particular environmental ones, associated with its slow decomposition and problems with recycling. Therefore, it is necessary to study packaging materials and apply holistic approaches to assessing the environmental performance of packaging made from them.

Modern trends in the production of cardboard packaging are primarily focused on consumer requirements. Researchers [7] include the following trends in cardboard packaging: sustainable development, minimalism, interaction with customers and adaptation to the needs of e-commerce. However, there is no emphasis on the importance of such indicators of cardboard packaging as deformation characteristics of materials, resistance to local and local loads. After all, they satisfy the needs of consumers in the reliability and safety of packaging.

The popularity of "green packaging" is growing among consumers, which ensures sustainable development and ecology. The work [8] emphasizes the factors that make cardboard packaging an important tool for achieving environmental goals. The emphasis is on using the minimum amount of materials, optimizing the size of packages to ensure their durability during operation and resistance to external mechanical influences. However, the problems of choosing cardboard for the manufacture of packages, taking into account their deformation and strength characteristics, remain unresolved.

The study [9] emphasizes the importance of cardboard packaging for agricultural products to withstand compression deformations. The best indicator of the strength of corrugated cardboard packaging against compression along the perimeter of the box is the generally accepted ECT indicator. The authors propose to use finite element modeling, which can replace the edge compression test of the packaging. The values of the indicator are explained by the approximate values of the thickness of the layers of corrugated cardboard. Therefore, effective measurement or prediction of the strength of packaging is crucial for the design of more efficient corrugated boxes for food, agricultural and industrial products. The emphasis in the work [10] is on the study of existing approaches to the life cycle assessment of packaging for fish and meat products. The environmental benefits of new food packaging systems are investigated. It is shown that environmentally friendly packaging systems serve as a catalyst for achieving the minimization of negative environmental impacts. It is precisely for the implementation of such an approach that it may be appropriate to study the performance indicators of cardboard packaging that is environmentally friendly and capable of recycling.

It is known that packaging manufacturers use printing technologies for their decoration. The study [11] reveals the influence of the characteristics of coated, uncoated paper and OPP film on the impression quality and color of flexographic images. Recommendations are given on the specific interaction between different substrates and printing paints. However, offset printing technology is also used for the decoration of packaging materials, which requires detailed studies, in particular, water absorption and solvent migration from printing impressions.

The migration of solvents from printing impressions to packaged products through the printed substrate is undesirable, so many researchers are studying the factors that affect it. A comparison of migration mechanisms in flexographic, gravure and digital printing on packaging for the food industry is given in [12]. However, the problems of migration processes from cardboard offset printing impressions to the contents of the packaging remain unresolved. An option to overcome these difficulties may be to study the influence of temperature and time on global migration from impressions on packaging cardboards [13]. It was found that increasing the temperature (from 25°C to 150°C) and increasing the time interval from the moment of obtaining the impressions leads to an increase in the global migration of marking chemicals obtained from offset impressions by 2.5 times. All these studies link the mechanism of solvent migration to printed packaging in general with the structure of paint systems. After all, it is known that traditional offset paint contains oils, impurities, pigments, fatty acid ethers, resins, etc., which can penetrate into the packaged goods.

However, the influence of the structure of cardboards on migration processes, a large assortment of which is widely used for the manufacture of packaging, remains unstudied. It can be assumed that the internal structure of cardboards also participates in the migration of solvents from printing impressions.

Despite the available research, no single systematic approach has been formulated to assess the relationship between the structure of cardboard and the operational properties of imp ressions. This necessitates the study of deformation characteristics, the structural structure of cardboard and their influence on the migration processes of harmful substances from impressions. The results of such a study can be recommended to product manufacturers for the selection of safe and environmentally friendly cardboard for the manufacture of packaging.

3. The aim and objectives of the study

The aim of the study is to determine the influence of the structural structure of cardboard on the deformation and strength characteristics of offset printing impressions and the migration of solvents from them. This will ensure the quality of the manufactured packaging and the safety of packaged products.

To achieve this aim, the following objectives were accomplished:

– to determine the influence of the type of cardboard on the water absorption of offset printing impressions obtained using low-migration paint;

– to investigate the structure of cardboard using electron microscopy and establish its influence on the consumer properties of packaging;

– to determine the level of solvent migration from printing impressions using gas chromatography and analyze its dependence on the internal structure of cardboard;

– to determine the influence of the internal structure of cardboard on the strength characteristics of offset printing impressions, in particular on the breaking force, relative elongation at break, the ratio of plastic and elastic deformation and burst strength.

4. Materials and methods of study on the packaging quality

4. 1. The object and hypothesis of the study

The object of the study was printing impressions for the production of cardboard packaging.

The hypothesis of the study was to confirm the influence of the structural structure of cardboard on the characteristics of printing impressions, in particular their strength, deformation and migration of solvents from paints.

4. 2. Research materials used in the experiment

The research materials were impressions on cardboard: Alaska Plus GC2 (Poland) (sample 1), Alaska Strong GC2 (Finland) (sample 2), AllyKing GC1 (China) (sample 3), Multicolor Spezial GD3 (Austria) (sample 4), from which the packaging was made. The characteristics of the cardboard are given in Table 1.

The cartons were printed on a Rapida 106 offset press using MGA NATURA paints (Huber Group). This series of special triad printing paints is designed to produce neutral impressions that do not affect the taste, smell or other organoleptic properties of the food products with which they come into contact.

The fastness properties of MGA NATURA paints according to ISO 12040/ISO 2836 are given in Table 2.

Table 1

Characteristics of cardboard [14–18]

Cardboard	Alaska Plus GC2	Alaska Strong GC2	AllyKing GC1	Multicolor Spezial GD3
Weight, g/m^2	235	245	250	300
Coated coating	Double	Double	Double	Three-layer
Top layer	Bleached chemical cellulose	Bleached chemical cellulose	Bleached chemical cellulose	Waste paper
Middle layer	BCTMP/CTMP	BCTMP	CTMP	Waste paper and mechanical pulp
Bottom layer	Bleached chemical cellulose	Bleached chemical cellulose	Bleached chemical cellulose	Waste paper
Gloss, % TAPPI	> 40	> 40	40	< 40
Hardness, Taber (15°) MD (mNm) – ISO 2493	16	17.8	15.8	20.5
Hardness, Taber (15°) CD (mNm) – ISO 2493	7.7	8.5	8.4	9.3
Roughness, μm	< 1.3	< 1.3	< 1.6	< 1.7

Table 2

Fastness properties of MGA NATURA paints

Paint characteristics	Lightfastness	Alcohol (IPA)	Nitrofastness	Alkalifastness	Oxidation/drying
Yellow 41MGA 5250	5	+	+	+	drying
Magenta 42 MGA 5250	5	+	+	-	drying
Cyan 43 MGA 5250	8	+	+	+	drying
Black 49 MGA 5250	8	+	+	+	drying

One of the main advantages of MGA NATURA is its very low migration rate, which minimizes the risk of harmful chemicals migrating from printed matter to food packaging.

4. 3. Research on water absorption of cardboard by the Cobb method according to DSTU 3549-97

The research was carried out on the PC-OE device under the following conditions: duration of water penetration – 60 seconds; duration of direct contact of paper with water, *s* – 45 ± 1; time after which the cardboard is dried with filter paper, *s* – 60 ± 1.

The water absorption of cardboard $Cobb_{60}$ (g/m^2) was calculated by the formula

$$Cobb_{60} = 100 \times (m_2 - m_1), \quad (1)$$

where $Cobb_{60}$ – water penetration capacity of cardboard in 60 s, g/m^2; 60 – contact time of cardboard with water, s; m_1 and m_2 – masses of cardboard samples respectively before and after contact with water, g.

To check the reliability of the results, five parallel studies were conducted.

4. 4. Electron microscopic research method

The study of the structure of the cardboard impression in cross section was carried out in a SELMI ПЭМ-100-01 transmission electron microscope using ultra-thin sections and in a JEOL T220A scanning electron microscope (Japan). Images of the sample surface were obtained at magnifications of ×1,500.

4. 5. Chromatographic research method

To determine the residual amount of chemical substances present on the printed impressions, the gas chromatography method was used using a Clarus 500 chromatograph from PERKIN ELMER. Samples with a maximum printed surface size of 100 cm^2 (with a tolerance of ± 0.5 mm) were prepared from the impressions for analysis.

Table 3 shows the values of the parameters that were taken into account in the process of chromatographic research.

Table 3

Gas chromatography parameters

Oven temperature	80°C
Needle temperature	80°C
Transfer temperature	150°C
Cycle time	18 min
Thermal transfer time	20 mon
Pressure time	1 min
Pressure	160 kPa

Identified substances on the printed impressions are displayed on the chromatogram, the peaks of which determine the concentration of organic solvents present.

4. 6. Method for determining the breaking force and tensile strength of cardboard before breaking

The method involves cutting out 5 strips 15 ± 0.5 mm wide in the transverse and machine directions of the fibers from a sheet of cardboard. Using a metal ruler and a thickness gauge, measure the width a with an accuracy of 0.1 mm and the thickness b with an accuracy of 0.01 mm of each sample.

On the XLW G6 tearing machine, cardboard strips are torn at a speed of movement of the lower clamp of the machine of 120 mm/min. This device complies with national and international standards: ISO 37, ASTM E4, ASTM D828.

The method for determining the breaking force and relative elongation of cardboard before breaking involves cutting five samples from a sheet in the form of strips 15 ± 0.5 mm wide in the machine and transverse directions of the fibers. The width of the samples was measured with a metal ruler with an accuracy of 0.1 mm, and the thickness with a thickness gauge with an accuracy of 0.01 mm. The tests were carried out on an XLW G6 tearing machine with a lower grip speed of 120 mm/min. The device meets the requirements of international standards ISO 37, ASTM E4 and ASTM D828. The samples were fixed between two grips that diverged during testing; the force was measured by a dynamometer mounted on a movable grip, and the movement was recorded by a built-in sensor. The error in force measurement did not exceed 0.5% of the indicator. Professional software provided automatic signal recording and statistical analysis of the results. The breaking force and elongation at break were determined based on the processing of experimental data.

The tensile strength of cardboard σ_t (MPa) is determined by the force *P* (N) per unit cross-sectional area (mm^2) at which the cardboard breaks. The calculation of σ_t (N/mm^2) was performed only for cardboard with a transverse fiber direction according to the formula

$$\sigma_t = \frac{P}{S}, \quad (2)$$

where *P* – the tensile force in the transverse direction of the fiber, N; *S* – the area in mm^2.

The arithmetic mean of at least five values was taken as the measurement result.

Determination of the tensile length (L) of the cardboard.

Based on the experimentally determined tensile force in two different directions, the tensile length is calculated by the formula

$$L = \frac{P \times k}{a \times m}, \quad (3)$$

where *L* – the tensile length, m; *P* – the tensile force, gs; *a* – the strip width (0.015 m); *k* – the correction factor for air humidity; *m* – the mass of 1 m^2 of the tested cardboard, g.

Calculate the tensile length separately for the machine L_m and transverse L_t directions using the average values of the tensile forces.

Determination of the anisotropy coefficient.

The anisotropy coefficient is calculated by the formula

$$K_a = \frac{L_m}{L_t}. \quad (4)$$

Calculation of the effective tensile modulus.

It is known that the modulus is the amount of stress per unit of relative deformation. In this case, it is the ratio of the tensile strength σ_p (N/mm^2) to the relative tensile deformation of the cardboard strip (ε):

$$\varepsilon = \frac{\Delta l}{L_o},$$

$$E_{ef} = \frac{\sigma_t}{\varepsilon}, \quad (5)$$

where l – the elongation of the cardboard strip at break in the transverse direction, mm; L_0 – the length of the strip between the clamps of the tearing machine (100 mm).

4. 7. Methodology for determining the deformation properties of cardboard under compression

The study was conducted on the I3B-1 device. Stress σ (N/m^2) is calculated by the formula

$$\sigma_t = \frac{F}{S}, \quad (6)$$

where F – the load value, kgf; S – the area of the cardboard load (equal to 3×10^{-6} m^2).

The relative compression deformation ε_{comp} (%) of the cardboard is calculated by the formula

$$\varepsilon_{comp} = \frac{100 \times \left(h_0 - j_p\right)}{h_0}, \quad (7)$$

where h_0 – the initial thickness of the cardboard, mm; h_p – the thickness of the cardboard at a certain load, mm.

The compression modulus E (N/m^2) of the cardboard is calculated by the formula

$$E_{comp} = \frac{\sigma}{\varepsilon_{comp}}, \quad (8)$$

where σ – the stress, N/m^2; ε_{comp} – the relative compression deformation (entered into the formula in fractions of a unit, not in percent).

The values of the elastic-plastic $\varepsilon_{el\text{-}pl}$ and plastic ε_{pl} deformation of the cardboard are calculated, respectively, by the formulas:

$$\varepsilon_{el\text{-}pl} = \frac{100 \times \left(h_{p=0} - h_p\right)}{h_0}, \quad (9)$$

$$\varepsilon_{pl} = \frac{100 \times \left(h_0 - h_{p=0}\right)}{h_0}. \quad (10)$$

The share of each type of deformation (%) in the relative compression deformation ε_{comp} is calculated by the formulas:

$$D_{el\text{-}pl} = 100 \times \left(\frac{\varepsilon_{el\text{-}pl}}{\varepsilon_{pl}}\right), \quad (11)$$

$$D_{pl} = 100 \times \left(\frac{\varepsilon_{el}}{\varepsilon_{comp}}\right), \quad (12)$$

Determining the share of plastic and elastic-plastic deformation is a critically important task for manufacturers of materials and packaging from them. The value of the magnitude of each type of deformation allows to predict how the material will behave under load and whether it will retain its functionality in the finished packaging.

4. 8. Methodology for determining the value of the resistance to burst of cardboards

To study the determination of the value of the resistance to burst of cardboards and packages made from them, a device was used (patent of Ukraine No. 58827) [14]. According to DSTU EN ISO 2759:2022; DSTU ISO 2759:2007 "Cardboard. Determination of the burst resistance", the following are determined:

1. Absolute burst resistance to crushing P_0, kPa

$$P_0 = \frac{S_p}{n}, \quad (13)$$

where S_p – the sum of the manometer readings for all tests; n – the number of tests.

2. Relative burst resistance, reduced to the conditional mass of products with an area of 1 m^2 100 g P_w, kPa

$$P_w = \frac{P_0 \times 100}{m}, \quad (14)$$

where m – the mass of cardboard with an area of 1 m^2, g.

3. Burst index X, kPa/g

$$X = \frac{P_0}{m}. \quad (15)$$

The burst resistance of cardboard and impressions on it allows to assess their strength and ability to withstand external pressure without destruction. This indicator is critically important for the production of packaging. It is the burst resistance that plays an important role in the correct selection of the material. The higher the burst resistance, the higher its marking index. Also, the burst resistance of cardboard helps to control technological processes in the production of packaging products. After all, the value of this indicator is affected by the density, humidity and internal structure of cardboard.

5. Results of studies of operational indicators of printing impressions for the production of cardboard packaging

5. 1. Results of studies of the influence of cardboard on the water absorption index of printing impressions

The results of studies of water absorption of cardboard impressions according to the Cobb$_{60}$ index (Fig. 1) showed that the lowest value is for AllyKing brand cardboard – 6.85 g/m^2.

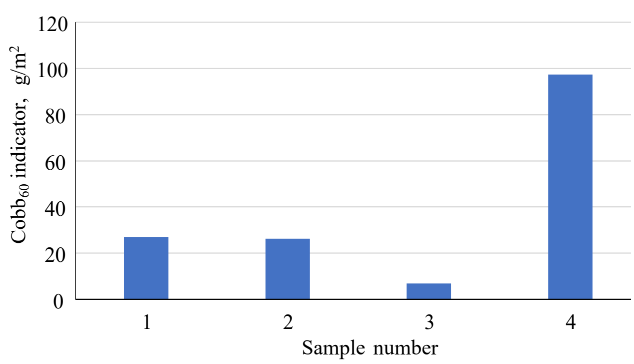


Fig. 1. Water absorption diagram of the studied cardboard impressions according to the Cobb method

Therefore, such cardboard has high water resistance and is suitable for use in conditions of high humidity, for example, for the production of packaging for food products, beverages or goods stored in humid environments. Alaska Plus and Alaska Strong cardboards are characterized by an average level of water absorption – 27.15 g/m^2 and 26.35 g/m^2, respectively. Therefore, such cardboards can be recommended for the production of packaging that will be in dry conditions and with short-term contact with water.

The highest level of water absorption is observed in the impression from Multicolor Spezial cardboard (97.35 g/m^2). Such cardboard quickly absorbs moisture, which can lead to a decrease in its strength, deformation or delamination. According to the results of increasing water absorption, the studied cardboards can be placed in a row:

AllyKing (6.85 g/m^2) > Alaska Strong (26.35 g/m^2) >
> Alaska Plus (27.15 g/m^2) > Multicolor Spezial (97.35 g/m^2).

5. 2. Electron microscopic studies of the influence of the structure of cardboards on the consumer properties of packaging

Studies of cross-sections of impressions on Alaska Plus cardboard confirmed its multilayer nature.

Packaging cardboards are characterized by a multilayer structure, which determines their physical, mechanical and printing properties. The front surface contains a two-layer chalked coating based on mineral pigments (kaolin or calcium carbonate) bound by polymer binders. This coating reduces porosity, limits paint absorption and provides high whiteness and gloss. The main layer consists of primary cellulose fibers, supplemented with bleached chemical-thermomechanical pulp (BCTMP) and chemical-thermomechanical wood pulp (CTMP), which allows to reduce the weight of the cardboard while maintaining rigidity. The back layer is uncoated, formed from less bleached cellulose fibers, has a light cream shade and provides stability of geometric dimensions and the required level of material stiffness (Fig. 2, *a*).

Alaska Strong cardboard (Fig. 2, *b*) is characterized by a similar multilayer structure. The inner layer, formed from virgin cellulose fibers, is the main carrier of mechanical strength and stiffness. Compared with other tested samples, this layer has a greater thickness and density, which causes increased resistance of the cardboard to bending and deformation.

Microscopic studies of cross-sections of impressions on AllyKing cardboard show that this is a multilayer material of class GC1 with two-layer coating. The cardboard structure consists of tightly interwoven microfibrils, from high-quality virgin cellulose fibers, with the addition of chemical-thermomechanical wood pulp (CTMP). These fibers are tightly interwoven, creating a strong but loose structure. It is thanks to CTMP that the cardboard has a high volume at a low density, which makes it stiff but light. This layer is responsible for mechanical properties such as bending strength and resistance to delamination.

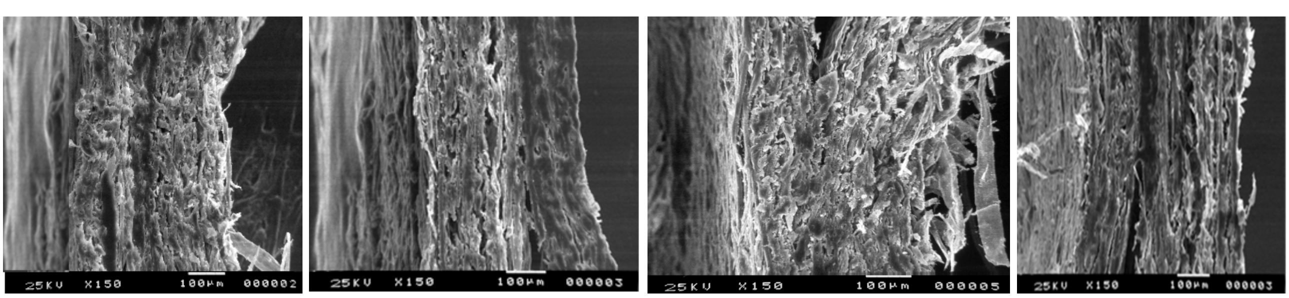
The microstructure of the back layer is less smooth than that of the front layer. It consists of less bleached cellulose, which provides additional rigidity and stability. The voids of the microfiber space are filled with the filler unevenly, large aggregates of its particles are observed, which clog the pores, leaving small gaps from 0.2 to 1 μm and reducing its porosity (Fig. 2, *c*).

Electron microscopic studies (Fig. 2, *d*) of cross-sections of impressions on Multicolor Spezial cardboard showed that its microscopic structure consists of three layers, each of which plays its own role in ensuring its properties. The face layer has a triple chalk coating, which microscopically looks like a very dense, uniform film consisting of mineral pigments (e.g. kaolin, calcium carbonate) and binders. They fill all the irregularities and pores formed by the base fibers. The middle layer is the thickest and is responsible for the strength and rigidity of the cardboard. It consists of primary fibers of chemical-thermomechanical wood pulp (CTMP), which are intertwined into a dense, but at the same time loose structure (Fig. 2, *d*). The use of CTMP gives the cardboard high rigidity at low weight, which makes it economically advantageous for packaging. This layer provides cardboard impressions with resistance to bending, which prevents deformation of the packaging. The back layer provides overall structural stability and strength of the cardboard, preventing its delamination and deformation.

The results of electron microscopic analysis confirmed the presence of a complex internal structure of cardboard, which is formed by the interweaving of fibers and a system of physicochemical bonds between them. It was established that the morphological features of the material determine the water-absorbing properties of printed impressions and significantly affect the operational performance of packaging. The data obtained indicate that the structure of cardboard determines the mechanical and printing characteristics of impressions, as well as the level of solvent migration from the paint layers.

5. 3. Results of determining the impact of packaging cardboard on the migration of chemical solvents from printing impressions

Today, in the world, considerable attention is paid to the environmental friendliness of materials for the manufacture of packaging. The requirements for the safety and environmental friendliness of packaging are determined by international ISO standards. There is a special regulatory framework in each country that regulates and controls the safety of packaging, which manufacturers must comply with in order to ensure the quality of packaged products and meet consumer requirements.



a *b* *c* *d*

Fig. 2. Microphotographs of cross-sections of the studied impressions on cardboards of the following brands: *a* – Alaska Plus; *b* – Alaska Strong; *c* – AllyKing; *d* – Multicolor Spezial

Therefore, general mandatory and specific requirements are imposed on packaging materials that apply only to the packaging of products for a specific purpose. These may be certain sanitary and hygienic or barrier requirements, which should be especially taken into account in cases where packaging is intended to be decorated by printing. One of the main functions of packaging is to provide a chemically neutral barrier between the contents and the external environment in order to prevent unwanted migration of substances and preserve product quality. Indeed, with poorly selected substrates, chemical components of printing paints, varnishes (mineral oils, polymers, ethers, benzophenols, etc.) can migrate from printing impressions to packaged products. This can cause their deterioration, change organoleptic properties, and also cause harm to the health of the consumer.

Therefore, it is important to study the impact of migration of printing paint components from printing impressions. The most important factors in analyzing the content of solvents evaporating from the printing impression are the measurement of ethanol, isopropanol, propanol and ethyl acetate. In addition, EU Regulation No. 1935/2024 establishes requirements for all materials that come into contact with food.

The results of gas chromatography studies of paint impressions obtained with MGA NATURA offset paints are presented in Table 4.

Table 4

Presence of solvents in printing impressions

Cardboard	Multicolor Spezial GD3 (300 g/m^2) (pattern 4)	Alaska Plus GC2 (235 g/m^2) (pattern 1)	Alaska Strong GC2 (245 g/m^2) (pattern 2)	AllyKing GC1 (250 g/m^2) (pattern 3)
Ethanol [mg/m^2]	11.3949	18.1753	20.5344	22.4737
Isopropanol [mg/m^2]	1.3682	0.6006	1.7482	4.4366
Propanol [mg/m^2]	1.5498	0.4683	3.3686	5.3423
Ethyl acetate [mg/m^2]	2.4918	5.8364	3.1266	9.5028
Isopropyl acetate [mg/m^2]	0.0915	0.1450	0.2209	4.9958
Propyl acetate [mg/m^2]	0.0783	0.1083	0.5891	1.6487
1-Ethoxy-2-propanol[mg/m^2]	0	0.0115	0.0147	0.0462

These solvents were detected in certain quantities in each offset impression sample. The largest amount of ethanol was detected on AllyKing and Alaska Strong cardboard (22.4737 and 20.5344 mg/m^2, respectively). The lowest migration of solvents from impressions on Multicolor Spezial cardboard. Isopropyl acetate and propyl acetate are practically absent in impressions on this cardboard (0.0915 and 0.0783 mg/m^2). There is absolutely no migration of such an organic solvent as 1-ethoxy-2-propanol. This is obviously due to the presence of a three-layer coated layer, which restrains migration processes. Therefore, such cardboard can guarantee the greatest safety of packaged food products. The presence of bleached chemical-thermomechanical pulp and chemical-thermomechanical wood pulp in the structure of Alaska Plus cardboard allows solvents to penetrate less from the impressions to the contents of the packaging compared to Alaska Strong cardboard.

5. 4. Results of determining the performance indicators of printed impressions

5. 4. 1. Determination of the breaking force and tension of the studied cardboards

The results of studies of the breaking force of the studied cardboard impressions, presented in Table 5, show that the greater the tension Δl of the cardboard impression, the greater its ability to compensate for external influences without destruction (Alaska Plus cardboard). Also, high tension in the transverse direction reduces the risk of ruptures during deformations.

Table 5

The values of the breaking force of the studied cardboard impressions

Sample No.	Transverse direction		Machine direction		Anisotropy coefficient K_a
	Tearing force P_n, gs	Tearing length L_n, m	Tearing force P_n, gs	Tearing length L_n, m	
1	10.7	3.03	18.0	5.11	1.68
2	10.2	2.89	12.2	3.46	1.19
3	10.8	2.88	13.4	3.57	1.24
4	9.9	2.2	12.9	2.86	1.3

The tensile stress *Δl*, mm in the transverse direction of the cardboard affects the tensile strength; flexibility of the material; protection from damage.

In turn, the relative tensile deformation of the cardboard ε affects the elasticity of the material; resistance to shock loads; increases durability; protects against delamination. These parameters should be taken into account when choosing cardboard for certain types of packaging, which is intended to perform specific functions.

Fig. 3 shows the diagrams of the tensile forces of the studied impression samples.

The diagrams of the tensile strength of the studied offset impressions obtained on different cardboards, taking into account the transverse and machine directions, are shown in Fig. 4.

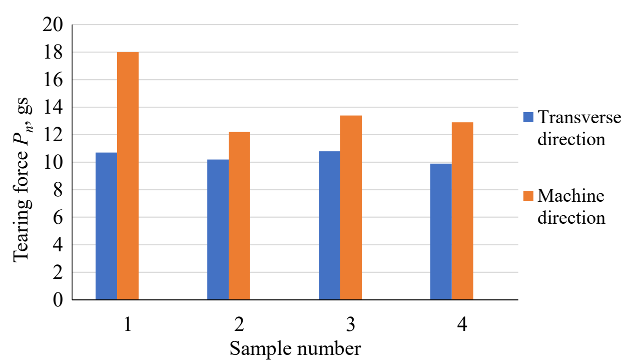


Fig. 3. Diagram of the breaking force of the studied samples of cardboard impressions

The tensile strength of cardboard impressions shows the maximum load they can withstand. Therefore, this indicator is very important for predicting the service life of packages made from these cardboards and should be taken into account by manufacturers when manufacturing a particular packaging design according to its functional purpose.

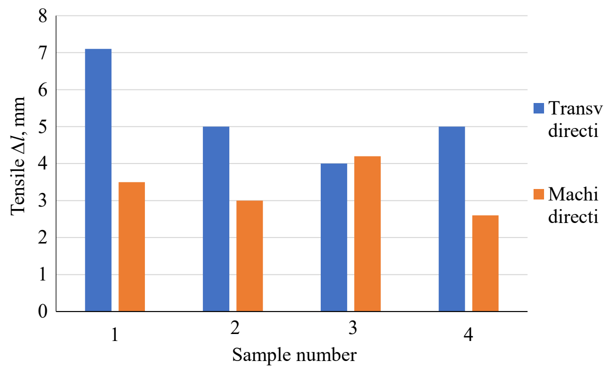


Fig. 4. Tensile diagram of the studied cardboard samples before rupture

High relative tensile deformation of cardboards indicates the ability of the material to absorb and distribute stress, reducing the risk of damage. Cardboard with a higher relative deformation is less prone to cracks when used in dynamic conditions.

The tensile strength of cardboard characterizes the strength of the material; it shows how resistant the cardboard is to destruction under the influence of tensile force. The tensile strength of cardboard depends on the structure of the cardboard fibers.

The type and orientation of the fibers (transverse or machine direction) also determine the strength of the material. Cardboard with well-bonded fibers has high tensile strength. This is an important indicator for packaging that is designed to withstand dynamic or static loads (for example, pressure during transportation or stacking).

Cardboard with a high tensile strength is recommended for the manufacture of packaging of various designs that can withstand significant loads.

5. 4. 2. Determination of the deformation properties of cardboard under compression

Compression deformation of cardboard under constant load affects the strength of the cardboard packaging structure. If the compression deformation is too large, the cardboard can lose its shape and mechanical properties. As a result, the packaging loses its load-bearing capacity, i.e. endurance. Too large a deformation can lead to a change in the geometric dimensions of the packaging, which will complicate its use, in particular during automated packaging, storage or transportation. Therefore, cardboard deformation affects the stability of the packaging dimensions. Compression deformation affects the loss of the material's resistance to mechanical wear, especially under cyclic loads. This is a critical characteristic, since the packaging is subjected to repeated loads, for example during transportation.

When subjected to compression deformation, cardboard packaging can lose its protective properties, which will lead to damage to the packaged product. It is known that a material with a lower compression deformation index under constant load is more reliable, durable and able to perform its functions better. If the packaging is stored in warehouses for a long time, it is important that the cardboard withstands the load without significant loss of its geometric parameters.

The compression deformation of cardboard is also affected by the internal structure of the cardboard, its density and thickness. Denser and thicker cardboard has less deformation. The compression deformation of cardboard, and accordingly the packaging, increases at high humidity, as the fibers become soft. An increase in temperature can reduce the rigidity of cardboard, increasing its ability to deform. Therefore, it is important to study the various types of deformation to which packaging cardboard is subjected. Table 6 presents the results of studies of the elastic-elastic and plastic deformation of cardboard.

The relative compression deformation of cardboard impressions under constant load is shown in the diagrams in Fig. 5.

Fig. 6 shows the diagrams of the determined compression modulus of the studied cardboard impressions.

Table 6

Definition of the elastic-plastic and plastic deformation of cardboard

Sample No.	Cardboard deformation, %			Distribution of deformations, %		
	Relative compressive strain ε_{comp}	Elastic-plastic $\varepsilon_{el\text{-}pl}$	Plastic ε_{pl}	D_{comp}	Elastic-plastic $D_{el\text{-}pl}$	Plastic $D_{pl.}$
1	12.023	1.466	10.557	100	12.193	87.806
2	12.790	1.162	11.627	100	9.085	90.906
3	5.730	1.433	4.293	100	24.991	74.938
4	5.769	1.602	4.167	100	27.769	72.213

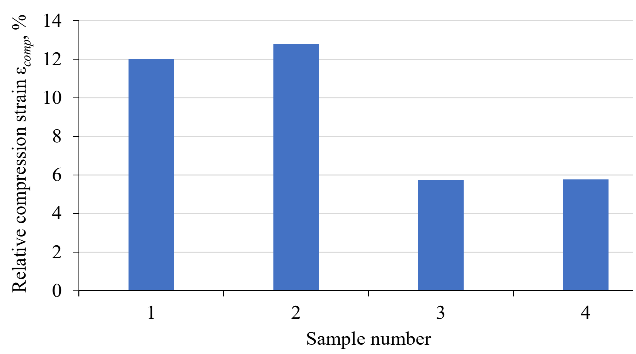


Fig. 5. Diagram of relative compression deformation of the studied cardboard impressions

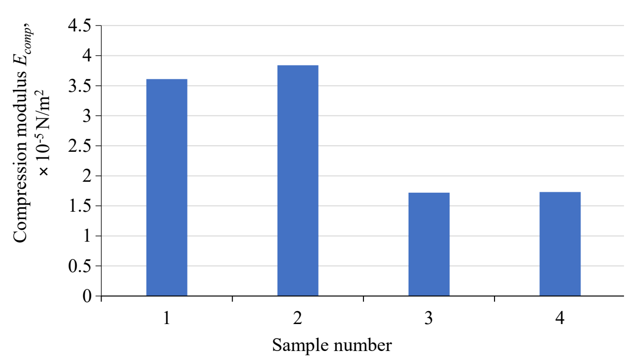


Fig. 6. Diagram of the compression modulus of the studied cardboards

The results of the studies, which are presented in Table 6 and in Fig. 5, 6, show that the compression deformation of cardboard under constant load affects its ability to maintain shape, strength and functionality under conditions of prolonged mechanical stress. The choice of cardboard with appropriate indicators is critically important for creating reliable packaging and its design.

According to the relative compression strain ε_{comp}, % and the corresponding compression modulus E_{comp}, N/m^2 of the studied cardboards, a series can be constructed from the highest to the lowest:

Alaska Strong (12.790%) > Alaska Plus (12.023%) >
> AllyKing (5.769%) > Multicolor Spezial (5.730%)

5. 4. 3. Determination of the value of the burst resistance of cardboard impressions

Determination of the value of the burst resistance of cardboard (English Burst Strength) is a key indicator of the strength of the material and characterizes its ability to withstand local load until failure. This parameter of cardboard affects such operational indicators as the strength of cardboard packaging, resistance to mechanical damage and loads (statistical or dynamic), etc.

The results of the studies showed that the structural structure of the fibers of the raw material affects the value of the burst resistance of cardboard impressions. Cardboards that are composed of long fibers have higher strength. The resistance to burst of cardboard depends on its density: a denser material provides better resistance to burst. At high humidity, the burst resistance of packaging cardboard decreases. The presence of layers of a coating on the surface of cardboard impressions increases their burst resistance. It can obviously be assumed that the value of this indicator depends on the type of connections between the interwoven fibers that make up the cardboard.

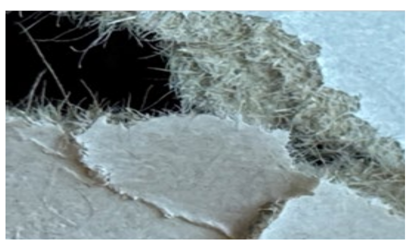
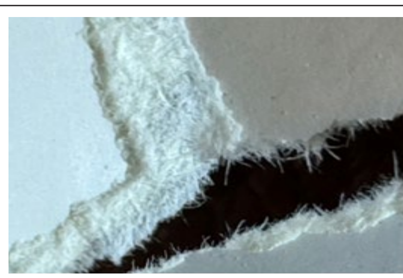
Table 7 shows the values of the burst resistance of cardboard impressions and micrographs of their destruction.

The highest burst resistance (90 kPa) is found in impressions on Alaska Plus cardboard, the lowest resistance (45 kPa) is found in impressions on AllyKing cardboard. Intermediate positions are occupied by impressions on Alaska Strong cardboard (50 kPa) and Multicolor Spezial (70 kPa).

As the analysis of micrographs shows, the inner layers look loose and less dense, compared to the outer ones, and have weaker bonds between the fibers. This may be the result of the use of recycled raw materials (waste paper), such as in Multicolor Spezial cardboard.

Table 7

Values of resistance and burst index of the studied cardboards and their micrographs

Cardboard/characteristics	Burst strength, kPa	Burst index X, kPa/g	Microphotograph of the destroyed front side	Microphotograph of the destroyed back side
Alaska Plus	> 90	0.38		
Multicolor Spezial	> 70	0.23		
Alaska Strong	> 50	0.21		
AllyKing	> 45	0.18		

At the break of the studied samples, an uneven surface is noticeable, demonstrating the natural fibrous structure of the cardboard. This is typical for materials based on cellulose fibers. The edges of the damage are uneven, which indicates local destruction due to point impact or high pressure. In some areas, the fibers look compressed, in others – stretched, which is the result of local burst and uneven loading. The destruction appears to be the result of a weak bond between the layers of cardboard. This may be due to insufficient sizing or weakness of the fibers.

To increase the burst resistance, it is worth: improving the adhesion between the layers, using denser or more glued inner layers; choosing raw materials with higher fiber strength for the inner and outer layers. This will increase the resistance of the cardboard to mechanical burst, reduce the risk of destruction and improve its performance.

6. Discussion of the results of the study of the performance indicators of offset printing cardboard impressions

The conducted experimental studies confirmed that determining the performance indicators of offset printing on cardboard is an important and relevant task. Taking into account the increased requirements of consumers for the quality of packaging, assessment of their durability and operational properties [4, 5], the water absorption index of cardboards was determined by the $Cobb_{60}$ method. It was found that the lowest water absorption index has an imprint on the AllyKing brand cardboard – 6.85 g/m^2, and the highest – 97.35 g/m^2 on Multicolor Spezial cardboard (Fig. 1).

The obtained water absorption indices provide important information about the properties of cardboards, their porosity and resistance to water. The water absorption indices of cardboards are consistent with their internal structural structure. Electron microscopic studies of cross-sections (Fig. 2) confirmed the multilayer structure of cardboard impressions. The structure of the cardboards differs from each other. The presence of bleached chemical-thermomechanical cellulose and chemical-thermomechanical wood pulp provides Alaska Plus and Alaska Strong cardboards with looseness and, accordingly, the same values of the Cobb60 index (27.15 g/m^2 and 26.35 g/m^2, respectively).

The inner layer of the impressions on these cardboards consists of virgin cellulose fibers, which provide them with strength and rigidity, high resistance to bending and deformation. Such characteristics are important when operating packages made from them.

Microscopic studies of cross-sections of AllyKing cardboard impressions showed the presence of various sizes of intertwined cellulose fibers and chemical-thermomechanical wood pulp. These fibers are tightly intertwined, preventing moisture from penetrating into the cardboard structure. This is confirmed by the lowest water absorption rate. Such a dense and strong cardboard structure provides the impressions with good mechanical properties, in particular, bending strength and resistance to delamination.

The microscopic structure of Multicolor Spezial cardboard consists of three layers, including waste paper. The presence of waste paper and mechanical pulp in the structure of Multicolor Spezial cardboard increases the water absorption index of the cardboard impression (among the samples studied, the $Cobb_{60}$ index is the highest).

Electron microscopic studies of cardboards confirmed the influence of their internal structure on the water absorption of impressions.

Chromatographic studies conducted showed that solvents migrate from each impression. Previous studies [11, 12] show the influence of paint systems and temperature on migration and do not take into account the internal structure of substrates. Electron microscopic studies of the internal structure of cardboards confirmed their influence on the migration of solvents from impression impressions.

The lowest migration of solvents from impressions was found on cardboard – Multicolor Spezial. Isopropyl acetate and propyl acetate are practically absent from impressions on this cardboard (0.0915 and 0.0783 mg/m^2), which is explained by the three-layer coated coating on its surface. It is packaging made of such cardboard that can guarantee the greatest safety of packaged food products. The largest amount of ethanol was found on AllyKing and Alaska Strong cardboard (22.4737 and 20.5344 mg/m^2, respectively). The presence of bleached chemical-thermomechanical pulp and chemical-thermomechanical wood pulp in the structure of Alaska Plus cardboard allows solvents to penetrate less from impressions to the contents of the package (Table 4). The results of solvent migration from impressions on Alaska Plus and Alaska Strong cardboard require more detailed studies. After all, these are cardboards with a double coated layer on the surface, but differ in their internal structure. Therefore, it would be advisable to further study the chemical composition of the coating on the front surface of these cardboards.

The tensile strength of cardboards and their tension before rupture were investigated. It was found that the greater the tension Δl of the cardboard and its relative deformation, the more it is able to compensate for external influences and distribute stresses, reducing the risk of damage to the impression. High tensile strength of cardboard in the transverse direction reduces the risk of rupture during deformations.

Determination of the tensile strength of the studied cardboards when stretched with the transverse direction of the fiber showed almost the same results, approximately 0.2 MPa (Fig. 3).

The highest index of relative compression deformation ε_{comp} in impressions on Alaska Strong and Alaska Plus cardboard (12.790% and 12.023%, respectively). The relative deformation of AllyKing and Multicolor Spezial cardboards is approximately two times lower (5.769% and 5.730%, respectively) (Table 6). A similar picture is characteristic of the determined compression moduli of the studied cardboard impressions (Fig. 6).

Determination of the deformation properties of cardboard under compression and constant load affects its ability to maintain shape, strength and functionality under conditions of prolonged mechanical stress.

Therefore, studies of the value of the burst resistance of cardboard impressions (Table 7) are important. Experiments have shown that the highest burst resistance is Alaska Plus cardboard. This characterizes the ability of such cardboard to withstand local (Fig. 6) load without damage. And therefore, the packaging made from it will meet these requirements. A somewhat lower burst resistance is provided by an impression made of Multicolor Spezial cardboard (70 kPa), which is explained by the presence of a three-layer coated coating on its surface. The lowest burst resistance is provided by an impression made of AllyKing cardboard (45 kPa), which is consistent with its highest water absorption rate and is obviously related to the internal structure.

Determination of the deformation properties of cardboard and impressions under compression and constant load affects its ability to maintain shape, strength and functionality under conditions of prolonged mechanical stress. The implementation of the obtained results in the production of cardboard packaging has practical significance, will contribute to increasing their durability, environmental friendliness and safety.

The presented research results have certain limitations in use, since they generally relate to the technology of manufacturing cardboard packaging using offset paints with low migration.

The shortcomings of the study include the establishment of cause-and-effect relationships between the type of paint system and the structure of cardboard on the occurrence of migration processes. This problem can be eliminated in the future using graph theory and modeling methods.

Assessment of operational indicators of printed impressions can be developed in the development of a methodology for determining integral quality indicators, which will take into account the strength, safety and environmental friendliness of cardboard packaging.

7. Conclusions

1. The results of studies on the water absorption of printed impressions confirmed the hypothesis about the influence of the internal structure of cardboards on the $Cobb_{60}$ index. The maximum water absorption index (97.35 g/m^2) is found on Multicolor Spezial cardboard with a three-layer coating and the presence of waste paper; and the minimum is found on AllyKing cardboard (6.85 g/m^2). For cardboards with a similar structural structure, the water absorption indicators are the same (Alaska Strong (26.35 g/m^2) and Alaska Plus (27.15 g/m^2). The presence of waste paper in cardboard increases the level of water absorption almost three times compared to cardboards made of bleached chemical-thermomechanical cellulose and thermo-mechanical wood pulp. Therefore, packaging is made of cardboard that quickly absorbs moisture, has lower strength, is capable of deformation and delamination.

2. Electron microscopic studies of cross-sections of cardboard impressions confirmed their multilayer structure. The interweaving of chemical cellulose fibers, thermo-mechanical wood pulp present in cardboards form stable physicochemical bonds that affect migration processes and deformation properties of impressions. Studies of the microscopic structure of cardboard impressions will help predict the strength and safety of packaging.

3. Based on chromatographic studies, migration was detected of various solvents from printing impressions. It is shown that the presence of a three-layer coated coating on cardboard helps to reduce the migration of solvents from impressions to packaged products. The value of the results obtained is to provide practical recommendations to manufacturers on the selection of cardboard for the manufacture of packaging. Taking into account the interaction of substrates and low-migration paints when selecting cardboard for offset printing will create safe conditions for packaged products, ensure the predicted durability of packaging and meet consumer requirements.

4. Determination of the magnitude of the breaking force and tension of the studied offset impressions confirmed the influence of the structural structure of the cardboard on them. An increase in the relative tensile deformation of cardboards, in particular in the transverse direction, reduces the risk of ruptures during deformations. The maximum relative compression deformation ε_{comp} is characteristic of impressions on Alaska Strong cardboard (12.790) and the smallest – AllyKing (5.730). The ability of cardboards to withstand and distribute loads reduces the risk of damage to the manufactured packages. It was found that the presence of recycled waste paper in Multicolor Spezial cardboard contributes to a reduction of almost half the relative deformation and compressive modulus. However, the presence of bleached chemical cellulose fibers and a three-layer coated coating in the cardboard structure leads to an increase in the burst resistance of the studied offset impression samples. The maximum burst resistance is observed in impressions on Alaska Plus cardboard (90 kPa) and Multicolor Spezial (70 kPa), the minimum in AllyKing cardboard (45 kPa). Therefore, packages made of Alaska Plus and Multicolor Spezial cardboard will be durable and resistant to external mechanical influences.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship or other, which could affect the study and its results presented in this article.

Financing

The study was conducted without financial support.

Data availability

The manuscript has no related data.

Use of artificial intelligence tools

The authors confirm that they did not use artificial intelligence technologies in creating the presented work.

References

1. Kawecka, A., Cholewa-Wójcik, A. (2017). Jakość opakowania jako determinanta bezpieczeństwa żywności w kontekście wymagań społecznych konsumentów. Zywnosc Nauka Technologia Jakosc/Food Science Technology Quality, 112 (3), 138–148. https://doi.org/10.15193/zntj/2017/112/205
2. Analiz rynku pakuvalnoi produktsiyi v Ukraini. Available at: https://inventure.com.ua/uk/analytics/investments/analiz-rinku-pakuvalnoyi-produkciyi-v-ukrayini
3. The Future of Global Packaging to 2028. Available at: https://www.smithers.com/services/market-reports/packaging/the-future-of-global-packaging-to-2028

4. Banterle, A., Cavaliere, A., Claire Ricci, E. (2012). Food Labelled Information: An Empirical Analysis of Consumer Preferences. International Journal on Food System Dynamics, 3 (2), 156–170. https://doi.org/10.18461/ijfsd.v3i2.325
5. Doslidzhennia: molod nadaie perevahu ekolohichniy upakovtsi. Available at: https://logist.fm/news/doslidzhennya-molod-nadaie-perevagu-ekologichniy-upakovci
6. Herbes, C., Beuthner, C., Ramme, I. (2018). Consumer attitudes towards biobased packaging – A cross-cultural comparative study. Journal of Cleaner Production, 194, 203–218. https://doi.org/10.1016/j.jclepro.2018.05.106
7. Johnson, C., Brown, E. (2019). Analysis of Cardboard Packaging Processing Techniques for Food Products. Food Packaging Technology, 5 (3), 210–225.
8. Barber, N. (2010). "Green" wine packaging: targeting environmental consumers. International Journal of Wine Business Research, 22 (4), 423–444. https://doi.org/10.1108/17511061011092447
9. Park, J., Park, M., Choi, D. S., Jung, H. M., Hwang, S. W. (2020). Finite Element-Based Simulation for Edgewise Compression Behavior of Corrugated Paperboard for Packaging of Agricultural Products. Applied Sciences, 10 (19), 6716. https://doi.org/10.3390/app10196716
10. Hanssen, O. J., Vold, M., Schakenda, V., Tufte, P.-A., Møller, H., Olsen, N. V., Skaret, J. (2017). Environmental profile, packaging intensity and food waste generation for three types of dinner meals. Journal of Cleaner Production, 142, 395–402. https://doi.org/10.1016/j.jclepro.2015.12.012
11. Valdec, D., Miljković, P., Auguštin, B. (2017). The influence of printing substrate properties on color characterization in flexography according to the ISO specifications. Tehnički glasnik, 11 (3), 73–77. Available at: https://hrcak.srce.hr/file/275270
12. Low Migration Inks Market by Process (Gravure, Flexography, Off-Set, Digital), End-Use Industry (Food & Beverages, Pharmaceutical, Cosmetics), and Region (North America, Asia Pacific, Europe, Rest of the World) - Global Forecast to 2022. Available at: https://www.marketsandmarkets.com/Market-Reports/low-migration-ink-market-63935492.html
13. Havenko, S. F., Ohirko, M. O. (2018). Vplyv struktury pakuvalnykh kartoniv na protses vzaiemodiyi z drukarskoiu farboiu ta mozhlyvu mihratsiyu yii skladovykh do upakovanykh produktiv. Suchasne reprodukuvannia: inzhynirynh, modeliuvannia, multy- ta krosmediini tekhnolohiyi: materialy naukovo-praktychnoho seminaru. Kyiv: KPI im. Ihoria Sikorskoho, 34–37. Available at: https://ela.kpi.ua/items/b56e07fe-966d-4115-a8f0-da0b6a35dd83
14. Havenko, S. F., Holovatska, N. V. (2010). Pat. No. 58827 UA. Zatysknyi mekhanizm dlia vyznachennia oporu prodavliuvannia kartonu i hofrokartonu. declareted: 07.10. 2010; published: 26.04.2011.
15. Lenyuk, G. K. (2017). The determination of linear correlation of board crushing resistance and its tear resistance in cross machine direction. Ukrainian Metrological Journal, 4, 65–68. https://doi.org/10.24027/2306-7039.4.2017.125520
16. Alaska Plus. Available at: https://www.icsfirpo.it/wp-content/uploads/2017/02/4-scheda-tecnica-alaska-plus.pdf
17. Alaska Strong. Available at: https://schramm-co.com/wp-content/uploads/2023/10/Alaska-Strong.pdf
18. Multicolor Spezial. Available at: https://www.gepkagit.com.tr/img/pdfs/karton/mm/MCS-Multicolor-Spezial.pdf