UDC655.326.1

STUDY OF FACTORS AFFECTING THE QUALITY OF FLEXOGRAPHIC IMPRINTS

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Flexographic printing is the leading method for producing flexible and label packaging; however, ensuring print quality stability remains a relevant scientific and practical challenge. This paper investigates the influence of flexographic process parameters on the quality of imprints on BOPP film, produced on a Mark Andy press using solvent-based Sun Chemical inks and photopolymer plates (150 lpi). Colour characteristics were assessed in the CIELAB colour space using an X-Rite SpectroEye spectrophotometer. A single-colour cyan test was used to determine the tonal value increase (TVI), and a four-colour CMYK test for press profiling. The TVI curves for magenta, yellow, and black inks are highly similar, while cyan shows a somewhat greater increase, correctable by adjusting printing unit pressure. Colour differences between the proof and production print (Ok-print) are ΔEab < 6 and ΔE2000 < 4, complying with ISO 12647-6 tolerances. The results confirm the effectiveness of the proposed press standardisation approach and individual colour profile construction.

***Keywords**: packaging, film, dot gain, flexographic press, profile, imprints, colorimetric indicators, quality.*

Problem statement. Flexographic printing firmly holds a leading position in the modern packaging and label industry. However, the high production speed and variety of substrates — from thin polymer films to corrugated board and aluminium foil — impose strict requirements on process stability. Any deviation from technological norms immediately results in rejects.

Quality control of flexographic imprints is not merely the final stage of production but a continuous process combining objective instrumental measurements and systematic analysis of technological parameters. Instability of the smallest halftone dots, deviations of colour characteristics from the reference, and imperfect gradation curves are the main challenges faced by flexographic enterprises when mastering new products and equipment. This issue is particularly acute when printing on polymer films, where ink behaviour differs significantly from traditional paper substrates [1, 2].

Analysis of recent research and publications. The quality of flexographic imprints and the factors shaping it are actively studied by the scientific community. The fundamental regulatory documents governing flexographic process parameters — from colour coordinates to gradation curves — are the ISO 12647-6 standard series [3, 4]. These standards establish permissible deviation ranges for optical density, tonal value increase, and colour difference ΔE, which serve as the basis for evaluating the quality of production imprints.

A significant contribution to the study of the influence of flexographic process parameters on print quality was made by Żołek-Tryznowska et al. [5], who investigated the effect of ink viscosity, plate type, and substrate on optical density and tonal value increase when printing on polymer films. The study confirmed the decisive influence of printing plate and substrate characteristics, while the effect of ink viscosity proved less significant for coverage areas of 40–100%.

In the flexographic printing process, the importance of selecting appropriate printing plates depending on the inks used is growing. Particular attention is paid to the compatibility of plates with water-based inks, which require specific surface properties [6]. Therefore, printing plates must possess appropriate hardness and water resistance, which directly affects print quality.

Havenko, Labetska and Telehina [1] studied the microstructure of flexographic imprints using optical and electron microscopy methods, establishing a relationship between halftone element parameters and colour reproduction quality. Further research by Havenko, Telegina and Wieczorek [2] demonstrated a significant influence of printing speed on the quality of flexographic imprints on PET film — specifically on tonal value increase, edge sharpness of halftone elements, and uniformity of ink application. Similar patterns were observed by other authors when studying flexographic print defects related to anilox roller parameters and the rheological properties of inks [7].

The issue of standardisation and profiling of flexographic presses has gained particular relevance in connection with the growing requirements for colour accuracy in brand colour reproduction in the packaging industry. Liu, Qiu and Ling [8] summarised mathematical models for dot gain compensation and proposed effective correction strategies that can be integrated into prepress preparation. Abusaq et al. [9] demonstrated the possibility of optimising the flexographic process using lean manufacturing methods and artificial intelligence to improve efficiency and quality stability. However, the issue of comprehensive standardisation of a flexographic press based on the construction of an individual colour profile when printing with solvent-based inks on BOPP film remains insufficiently studied, which determines the relevance of this work.

Aim of the research. The aim of the work is to investigate the factors affecting changes in image tonality and the quality characteristics of flexographic imprints on film materials.

Presentation of the main research material. The study objects were imprints produced on BOPP film using the flexographic method on a Mark Andy press. The characteristics of the materials and printing conditions are given in Table 1.

Table 1

Characteristics of materials and flexographic printing conditions

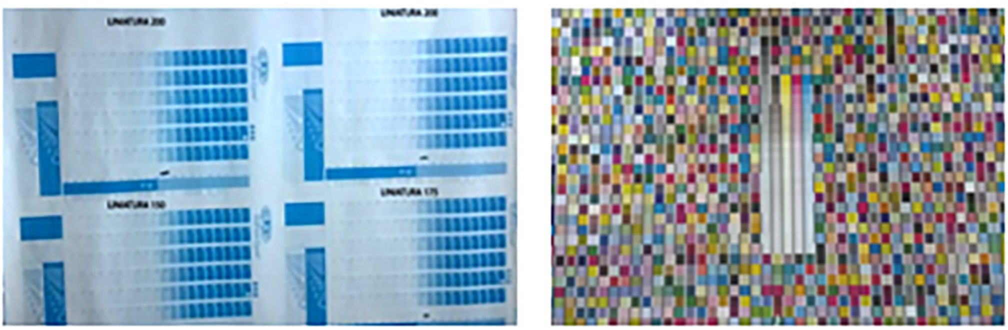
Parameter	Description	Value
Substrate	Film Type	Bopp
	Thickness	20 μm
	Roll Width	1250 mm
Ink	Type	Solvent-based, Sun Chemical
Printing Plate	Screen Ruling	150 Lpi
Anilox (CMYK)	Volume / Screen Ruling	3.3 cm³/m² / 524 l/cm

The colour coordinates of selected colour patches were measured using an X-Rite SpectroEye spectrophotometer in the CIELAB colour space. Measurement conditions: D50 light source, 0°/45° geometry, 2° standard observer, measurement on a black backing. The colour difference was calculated using the ΔEab and ΔE2000 formula:

$$\Delta E = \sqrt{[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]}, \quad (1)$$

where ΔL, Δa, Δb are the differences in lightness and chromaticity coordinates between the sample and the reference.

A single-colour test No. 1 (cyan channel) with a multi-tone halftone scale at screen angles of 7°, 22°, 37°, 52°, 67° and 82°, as well as negative and positive lines and text, was used to determine the tonal value increase. A four-colour test No. 2 was used for press profiling (Fig. 1).



Test 1 Test 2

Fig. 1. Test 1 for determination of tonal value increase and Test 2 for press profiling

Objective evaluation of imprint quality employs a set of parameters: optical density (D), tonal value increase (Dot Gain / TVI), ink registration accuracy (Register), colour difference (ΔE), and ink lay uniformity. Modern production verifies these parameters using densitometers, spectrophotometers, and automated inline video inspection systems – high-resolution cameras that scan the web directly during printing and compare the current imprint with the digital original artwork [3].

Most quality defects (dirty print, banding, ghosting, edge blur, show-through, mottle) have interrelated causes distributed across four groups: input materials (inks, varnishes, substrates), equipment (presses, plates, aniloxes, mounting tapes), technological parameters (viscosity, pressure, speed), and the human factor (staff qualification and experience) [2, 7].

The choice of printing plate type is of particular importance when printing on polymer films. Table 2 presents a comparative characterisation of elastomeric and photopolymer plates.

Table 2

Comparison of elastomeric and photopolymer printing plates

Characteristic	Elastomeric	Photopolymer
Durability	Higher resistance to abrasion and chemicals	Less durable, especially with aggressive inks
Detail accuracy	Suitable for large and medium-sized designs	Higher accuracy for fine details
Cost	Higher initial cost, but longer service life	Lower initial cost, shorter service life
Substrates	Ideal for thick, complex materials	Better suited for thin and smooth materials
Application	Optimal for solvent-based inks	Better suited for water-based and UV inks
Ecology	No chemicals required in production	Require chemical or water washout

The stability of the smallest printing dots and the characteristic print curve were analysed on imprints obtained after the first reprint. Visual evaluation of halftone dots showed that the smallest halftone dots in certain patches behave unstably during printing. Dot instability is particularly noticeable in the highlight range at a screen ruling of 150 lpi, which requires correction of the plate production process: exposure time and processing conditions.

The characteristic TVI curves for magenta, yellow, and black inks are highly similar. Only cyan ink showed a somewhat greater tonal value increase compared to the other inks, which can be corrected by adjusting the pressure in the corresponding ink application unit. The overall characteristic print curve is correct (Fig. 2).

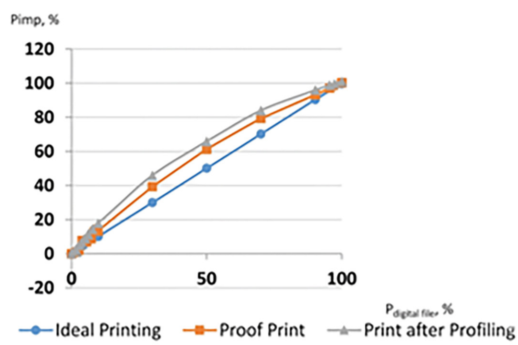


Fig. 2. Characteristic print curve for screen ruling 150 lpi

Fig. 3 presents the results of the study of tonal value increase (ΔP, %) on production imprints for all four CMYK inks at a screen ruling of 150.

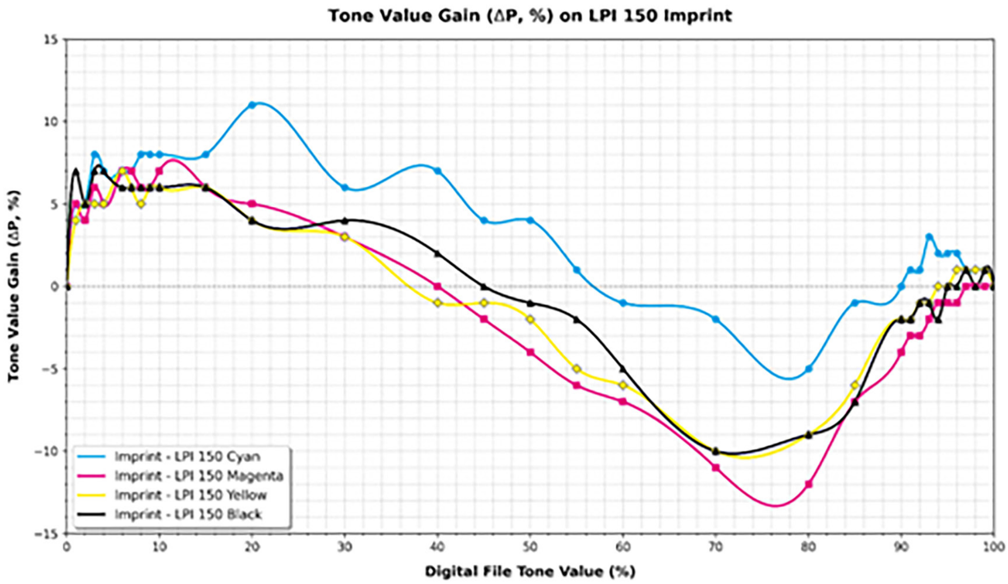


Fig. 3. Results of tonal value increase studies on production imprints

The graph shows that in the highlights (coverage 1–20%) all inks demonstrate a positive tonal value increase — from 4 to 11%, with cyan ink showing the maximum values. In the midtone range (40–60%) the opposite tendency is observed for magenta, yellow, and black: a negative increase indicates partial dot recovery, characteristic of elastic photopolymer plates. In the shadows (80–90%) the negative increase for colour inks is associated with dot merging and the corresponding loss of detail.

Based on the printed four-colour test No. 2, an individual profile was built for the Mark Andy flexographic press. An imprint printed with the added profile should reproduce the colours of the production imprint (Ok-print) as accurately as possible. To verify colour consistency, the colour differences ΔE*ab and ΔE*2000 between the main colour patches of the proof and production imprint were calculated (Table 4).

As shown by the data in Table 4, the obtained colour differences between the proof print and the production imprint (Ok-print) are within the tolerances stipulated by ISO 12647-6:2006 and ISO 12647-6:2012 [1, 2]: ΔE*ab < 6 and ΔE*2000 < 4 for all four CMYK inks. The greatest deviation was recorded for yellow ink (Y), which is typical of flexographic printing on transparent films and is explained by the increased sensitivity of the yellow channel to variations in ink layer thickness.

Conclusions. The standardisation of the printing process on the Mark Andy press consisted in the optimisation of printing plate production parameters, resulting in a flexographic plate that prints stably on the given press (stable dots in the highlights and an appropriate and uniform tonal value increase across the entire range of the multi-tone halftone scale).

Table 4

Colour differences between proof and production imprint

Ink	Imprint			Proof			ΔEab	ΔE2000	ISO 12647-6 Tolerance
	L	a	b	L	a	b			
C	58,56	-38,17	-50,57	55,55	−38,55	−55,26	3,616	3,075	≤ 6 / ≤ 4
M	49,01	77,41	-3,70	48,79	78,58	−1,19	2,760	1,040	≤ 6 / ≤ 4
Y	92,33	-0,30	97,44	97,56	−3,72	104,16	5,431	3,761	≤ 6 / ≤ 4
K	12,00	1,67	2,09	15,45	1,96	3,49	3,139	2,581	≤ 6 / ≤ 4

An important result of the standardisation process is the creation of an individual colour profile for the Mark Andy press. This profile was subsequently used to create a digital colour proof. The colour imprint printed using the colour profile accurately reproduced the colours of the production colour proof, as evidenced by small colour differences — ΔE*ab below 6 and ΔE*2000 below 4. This profile will be used by the printing house to create colour proofs for clients on the basis of which they approve the print job, and this proof will help the printing house achieve accurate production colours more quickly.

СПИСОК ВИКОРИСТАНИХ ДЖЕРЕЛ

1. Study of flexographic imprints using the methods of optical and electron microscopy / S. Havenko et al. Proceedings of SPIE. 2024. Vol. 12938. Art. 129380W. DOI: https://doi.org/10.1117/12.3012269.
2. Havenko S., Telegina T., Wieczorek M. The studies on the impact of the printing speed on the quality of flexographic prints performed on PET film. Packaging Review. 2025. No. 4. P. 16–22. DOI: https://doi.org/10.15199/42.2025.4.2.
3. ISO 12647-6:2006. Graphic technology — Process control for the production of half-tone colour separations, proofs and production prints — Part 6: Flexographic printing. International Organization for Standardization, 2006. 18 p.
4. ISO 12647-6:2012. Graphic technology — Process control for the production of half-tone colour separations, proofs and production prints — Part 6: Flexographic printing. International Organization for Standardization, 2012. 22 p.
5. Influence of some flexographic printing process conditions on the optical density and tonal value increase of overprinted plastic films / Z. Żołek-Tryznowska et al. Coatings. 2020. Vol. 10, no. 9. Art. 816. DOI: https://doi.org/10.3390/coatings10090816.
6. Scarpeta E. Fleksografia. Praktyczny Podręcznik. Warszawa : Zrzeszenie Polskich Fleksografów PLFTA, 2011. 320 s.
7. Overall equipment efficiency of flexographic printing process: A case study / S. Zahoor et al. IOP Conference Series: Materials Science and Engineering. 2017. Vol. 272. Art. 012015. DOI: https://doi.org/10.1088/1757-899X/272/1/012015.
8. Liu X., Qiu B., Ling Y.-L. Mathematical modelling and compensation strategies for printing dot gain. PLOS ONE. 2025. Vol. 20, no. 10. Art. e0334921. DOI: https://doi.org/10.1371/journal.pone.0334921.
9. Improving energy performance in flexographic printing process through lean and AI techniques: A case study / Z. Abusaq et al. Energies. 2023. Vol. 16, no. 4. Art. 1972. DOI: https://doi.org/10.3390/en16041972.

References

1. Havenko, S., Labetska, M., & Telehina, T. (2024). Study of flexographic imprints using the methods of optical and electron microscopy. Proceedings of SPIE, 12938, Article 129380W. https://doi.org/10.1117/12.3012269

2. Havenko, S., Telegina, T., & Wieczorek, M. (2025). The studies on the impact of the printing speed on the quality of flexographic prints performed on PET film. Packaging Review, 4, 16–22. https://doi.org/10.15199/42.2025.4.2

3. International Organization for Standardization. (2006). Graphic technology — Process control for the production of half-tone colour separations, proofs and production prints — Part 6: Flexographic printing (ISO Standard No. 12647-6:2006).

4. International Organization for Standardization. (2012). Graphic technology — Process control for the production of half-tone colour separations, proofs and production prints — Part 6: Flexographic printing (ISO Standard No. 12647-6:2012).

5. Żołek-Tryznowska, Z., Rombel, M., Petriaszwili, G., Dedijer, S., & Kašiković, N. (2020). Influence of some flexographic printing process conditions on the optical density and tonal value increase of overprinted plastic films. Coatings, 10(9), Article 816. https://doi.org/10.3390/coatings10090816

6. Scarpeta, E. (2011). Fleksografia. Praktyczny podręcznik. Zrzeszenie Polskich Fleksografów PLFTA.

7. Zahoor, S., Shehzad, A., Mufti, N., Zahoor, Z., & Saeed, U. (2017). Overall equipment efficiency of flexographic printing process: A case study. IOP Conference Series: Materials Science and Engineering, 272, Article 012015. https://doi.org/10.1088/1757-899X/272/1/012015

8. Liu, X., Qiu, B., & Ling, Y.-L. (2025). Mathematical modelling and compensation strategies for printing dot gain. PLOS ONE, 20(10), Article e0334921. https://doi.org/10.1371/journal.pone.0334921

9. Abusaq, Z., AlSyouf, I., Al-Refaie, A., & Awad, M. (2023). Improving energy performance in flexographic printing process through lean and AI techniques: A case study. Energies, 16(4), Article 1972. https://doi.org/10.3390/en16041972(Примітка: для точного APA 7 тут розкрито перших чотирьох співавторів замість «et al.»)

doi: 10.32403/0554-4866-2026-1-91-165-172

ДОСЛІДЖЕННЯ ЧИННИКІВ ВПЛИВУ НА ЯКІСТЬ ВІДБИТКІВ ФЛЕКСОГРАФІЧНОГО ДРУКУ

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Флексографічний друк є провідним методом виробництва гнучкої та етикеткової упаковки завдяки високій продуктивності, сумісності з широким спектром субстратів та економічній ефективності. Водночас забезпечення стабільності *якості відбитків у флексографічному виробництві залишається актуальною науково-практичною проблемою, особливо при друці на полімерних плівках, де поведінка фарби суттєво відрізняється від традиційних паперових субстратів. У статті досліджено вплив параметрів флексографічного процесу на якість відбитків, виконаних на плівці BOPP. Об'єктом дослідження були тиражні відбитки, виготовлені на флексографічній машині Mark Andy з використанням розчинних фарб Sun Chemical та фотополімерних форм із лініатурою 150 lpi. Анілоксові вали для всіх фарб характеризувалися об'ємом 3,3 $см^3/м^2$ та лініатурою 524 л/см. Колірні характеристики оцінювалися в просторі CIELAB за допомогою спектрофотометра SpectroEye X-Rite. Для визначення приросту растрової тональності використано одноколірний тест (блакитний канал) з растровою багатотоновою шкалою з кутами растра 7°, 22°, 37°, 52°, 67° та 82°, а для побудови профілю машини — багатоколірний тест CMYK. Встановлено, що характеристичні криві приросту тонального значення для пурпурової, жовтої та чорної фарб є максимально подібними, тоді як блакитна фарба демонструє дещо вищий приріст растрового тонального значення, що може бути скориговано регулюванням тиску у відповідному блоці нанесення фарби. Візуальна оцінка показала нестабільність найменших растрових точок у діапазоні світлих тонів, що вказує на необхідність оптимізації параметрів виробництва друкарської форми — часу експозиції та режимів проявлення. На основі багатоколірного тесту побудовано індивідуальний колірний профіль машини Mark Andy, який використано для створення цифрової кольоропроби. Колірні відмінності між пробним відбитком та виробничим друком (Ok-print) становлять $\Delta E_{ab} < 6$ та $\Delta E_{2000} < 4$ для всіх фарб CMYK, що відповідає допускам стандарту ISO 12647-6. Отримані результати підтверджують ефективність запропонованого підходу до стандартизації флексографічного процесу та побудови індивідуального колірного профілю машини, що дозволяє скорочувати час налаштування при виконанні нових замовлень і гарантувати клієнтам точне відтворення кольору.*

Ключові слова: *пакування, плівка, приріст растрової крапки, флексографічна машина, профіль, відбитки, колориметричні показники, якість.*

Стаття надійшла до редакції 17.05.2026.
Received 17.05.2026.
Стаття прийнята 22.05.2026.
Accepted 22.05.2026.
Опубліковано 30.05.2026.
Published 30.05.2026.