

Article

Assessment of Efficiency and Anilox-Roll Condition after Ultrasonic Cleaning

Kamila Przybysz ¹, Aneta Lipkiewicz ¹, Edyta Małachowska ^{1,2,*} , Marcin Dubowik ¹  and Piotr Przybysz ^{1,2}

¹ Natural Fibers Advanced Technologies, 42A Blekitna Str., 93-322 Lodz, Poland; kamila.przybysz@interia.pl (K.P.); an_eta12@wp.pl (A.L.); marcin.dubowik1989@gmail.com (M.D.); piotr_przybysz@sggw.edu.pl (P.P.)

² Institute of Wood Sciences and Furniture, Warsaw University of Life Sciences—SGGW, 159 Nowoursynowska Str., 02-787 Warsaw, Poland

* Correspondence: edyta_malachowska@sggw.edu.pl; Tel.: +48-22-593-85-45

Abstract: In the flexographic printing industry, anilox rolls play a pivotal role in determining ink usage. These rolls are characterized by anilox cells, which transfer ink to the final printed material. However, these rolls face wear and potential damage during their operational life, largely due to improper cleaning or debris accumulation in the ink duct. Such contamination compromises the ink capacity, impacting print quality. With the industry's need for consistent and high-quality prints, there is a growing emphasis on the development and consistent implementation of optimal anilox-roll operation methodologies. One cleaning method gaining traction is ultrasonic cleaning. This method employs ultrasonic waves in conjunction with a cleaning agent, providing a quick, efficient, and environmentally conscious cleaning alternative. Yet, there is limited scientific data on the actual condition of anilox rolls after ultrasonic cleaning. In this study, the surface of anilox rolls post-ultrasonic-cleaning was comprehensively examined using microscopic analysis. This assessment provided insights into the method's efficacy and potential for causing roll damage. The results showed that post-printing, rolls lost approximately 20% of their ink capacity, and ultrasonic cleaning effectively restored the ink capacity of the undamaged rolls. However, for rolls with pre-existing damage, the ultrasonic cleaning process exacerbated the damages, leading to complete delamination in some instances. This study underscores the potential of ultrasonic cleaning in restoring anilox-roll efficiency but also highlights the need for caution with damaged rolls.

Keywords: anilox roll; flexography; ink duct; raster mesh; ultrasonic anilox-roll cleaning machine



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1. Introduction

Flexographic printing primarily employs the anilox cylinder, a determinant of ink volume delivery. The anilox cells within these cylinders facilitate ink transfer to the print form and, ultimately, the substrate [1–4]. To cater to evolving market requisites, anilox-roll manufacturers have been progressively enhancing anilox cell densities alongside their depths and volumes. However, despite advanced solutions optimizing the functionality of these cylinders [5,6], they remain susceptible to wear [7–9] and operational damage [10–14].

Suboptimal cleaning processes often result in residue retention within the ink-well, leading to the deterioration of the anilox cell's depth and, subsequently, its ink-transfer capacity. Further complications arise due to the desiccation of ink remnants within the cells, which has implications for the ceramic surface of the roll. During printing, the ink tends to dry on the base and peripheries of the anilox cells, progressively diminishing the ink capacity [15–19].

Given the pivotal role of the inkwell capacity in determining ink-volume application, maintaining a consistent ink-well volume becomes paramount for accurate color representation. A decrease in the anilox cell's capacity leads to a notable reduction in ink transfer to

the substrate, which can result in a decline in printout optical density and shifts in color hues [20–22].

Ensuring the prolonged functionality of anilox rolls necessitates the development and consistent application of a robust operational methodology. Such practices aim to prolong roll functionality, maintain operational parameters, and minimize risks associated with substandard print quality. Notably, since a definitive timeframe for anilox roll replacement remains elusive, post-cleaning diagnostics of the roll condition, especially the surface responsible for ink dispensation, are essential. This diagnostic step should be ingrained within a comprehensive quality-control regime.

Effective anilox roll cleaning remains a priority for printing houses, as it correlates directly with enhanced roll longevity and ensures consistent ink transfer, thereby bolstering the printing stability and reproducibility. The importance of regular cylinder maintenance is well acknowledged within the printing community. Therefore, modern printing enterprises prioritize efficient and environmentally safe cleaning methodologies. However, numerous cleaning techniques can inadvertently damage anilox rolls, compromising their utility in the printing process [23]. Among the prevalent cleaning techniques [24–27] are chemical cleaning (both manual and automated) [28,29], sandblasting [30,31], laser cleaning [32,33], and ultrasonic cleaning [34].

Ultrasonic cleaning emerges as a frontrunner, considering its advantages of speed, efficiency, cost-effectiveness, and a low environmental footprint. This method employs a synergy of ultrasound waves (ranging between 16 kHz to 1 GHz) and cleaning agents. The roll, while rotating, is immersed in a heated chemical solution, such as caustic soda. The ultrasonic waves induce cavitation, generating gas bubbles. Upon bubble implosion against the anilox surface, the resultant pressure and temperature facilitate contaminant dissolution within the anilox cells [24,34]. Manufacturers of ultrasonic anilox cleaners claim that this technique ensures thorough cleaning while preserving roll integrity. It is noteworthy that ultrasonic cleaning demonstrates high efficacy across various flexographic inks. Additional merits include rapid installation, full automation, minimal water consumption, and a built-in circulation system for cleaning-agent reuse. Investment costs are relatively modest, and machines can be tailored to individual printing-house requirements. However, it is imperative to recognize that any ceramic degradation during ultrasonic cleaning is considered contamination, occasionally leading to ceramic chipping.

A comprehensive literature survey revealed a dearth of empirical studies and thorough analyses on anilox rolls post-ultrasonic-cleaning. The majority of the accessible information was predominantly sourced from commercial promotional material. However, this was very general information, not taking into account the process variables that affect the efficiency and effectiveness of the cleaning process. Given this knowledge gap, we deemed it pertinent to conduct an in-depth microscopic examination of anilox-roll surfaces post-ultrasonic-cleaning. This study aims to gauge the method's efficacy and its implications on the roll's surface characteristics and potential damage.

2. Materials and Methods

2.1. Anilox Rolls

For the research, custom-made ceramic cylinders were used. The cylinders were manufactured by Danex (Katowice, Poland). The parameters of the cylinders were as follows: 200 L/inch lineage, 15 cm³/m² ink capacity, 40 µm inkpot threshold width, and 80 µm inkpot opening width. The threshold-to-inkwell opening ratio should be 1:2. The coating material was Cr₂O₃, with a minimal coating thickness of 250 µm.

2.2. Printing Procedure

The printing procedure was performed using an IGT-F1 device (IGT Systems, Almere, The Netherlands). The Direct Print program with pre-inking was employed. The following parameters were used: printing speed of 0.5 m/s; anilox force of 200 N; printing force of 300 N; and 3 pre-ink revolutions. For each cylinder, 50 printing runs were conducted.

After each printing test, the roll was cleaned with a soft wet fabric to remove ink. After completing all the printing runs, the test roll was sent for further processing (microscopic assessment and cleaning). The ink used for the test was a yellow water-based ink.

2.3. Mechanical Damages

To induce mechanical damages to the anilox roll, the Rennstieg automatic center punch (Rennstieg Werkzeuge, Steinbach-Hallenberg, Germany) was used. The punching force was set to the lowest value, which was 20 N. For the cylinder with mechanical damages, 12 punches were made in different places on the printing area of the cylinder. After optical inspection, only local mechanical defects with an area similar to that of one inkpot were observed. No larger damages or delamination of the ceramic coating were observed.

2.4. Cleaning Procedure

A Polsonic 33 ultrasonic cleaner (POLSONIC Palczyński Sp. J., Warsaw, Poland) was used to clean the rollers. Cleaning was performed using a 10% aqueous solution of Recyl Quick Wash Booster Plus. The cleaning temperature was set at 30 °C, and the cleaning time was 10 min. The frequency and power of the ultrasonic cleaner were adjusted for cleaning anilox. The parameters were as follows: a frequency of 40 kHz; a power of 50 W/dm³. After cleaning with the chemical cleaner, the roller was thoroughly washed with distilled water and placed in an ultrasonic cleaner filled with distilled water for 1 min. Then, the roller was dried using compressed air with a pressure of 1 bar. A reference trial was performed without a cleaning agent.

2.5. Analysis of Anilox Rolls

Analysis of the anilox rolls was performed using an instrumental 3D optical microscopy technique, employing a Keyence VHX 7000 digital microscope (Keyence, Mechelen, Belgium) with a VH Z500 zoom lens (magnification 500–5000x), a Z20 lens (20–200 magnification), and a high-resolution VHX 7020 camera, in accordance with the ISO 25178:2016 standard [35].

Microscopic analyses were used to detect damage to the structure of the anilox ceramic surface caused by the cleaning process and to determine changes in the most important parameters describing anilox rolls, such as

- Ratio of the inkwell opening to the width of the threshold;
- Capacity, i.e., the volume of inkwell collected on a unit area of a raster mesh;
- Inkwell depth.

The obtained numerical data were subjected to statistical analysis. The results presented in the paper are average values of the data obtained for various randomly selected anilox-roller fields after conducting 3 parallel analyses.

The layout of the experiment procedure was as follows. Five anilox rolls were used:

1. Reference: brand new anilox roll, no mechanical damages, not printing, no cleaning;
2. No mechanical damages, printing, cleaning with a cleaning agent;
3. Mechanical damages, no printing, no cleaning;
4. Mechanical damages, printing, cleaning with a cleaning agent;
5. Mechanical damages, printing, cleaning with distilled water.

Microscopic analysis was performed after inducing mechanical damages, after printing (without cleaning), and after printing and cleaning.

3. Results and Discussion

The fundamental parameters for assessing anilox rolls are their lineage and ink-transfer capacity. In the study, standard rolls with a hexagonal mesh design were used, featuring a lineage of 200 L/inch and a manufacturer-declared capacity of 15 cm³/m².

In the research, the rolls were evaluated using a microscopic method, which involved comprehensive measurements of the following properties:

- Depth of the inkwell;
- Diameter of the inkwell;
- Volume of the inkwell;
- Surface area of the inkwell.

In the study, over 100 inkwells on each roll were analyzed during each assessment. The obtained results are presented as both the average value and the standard deviation value. For the inkwells in which intentional damages were introduced, the damaged areas were excluded from the calculated average values. The obtained results in graphic form are presented in the figures (Figures 1 and 2)

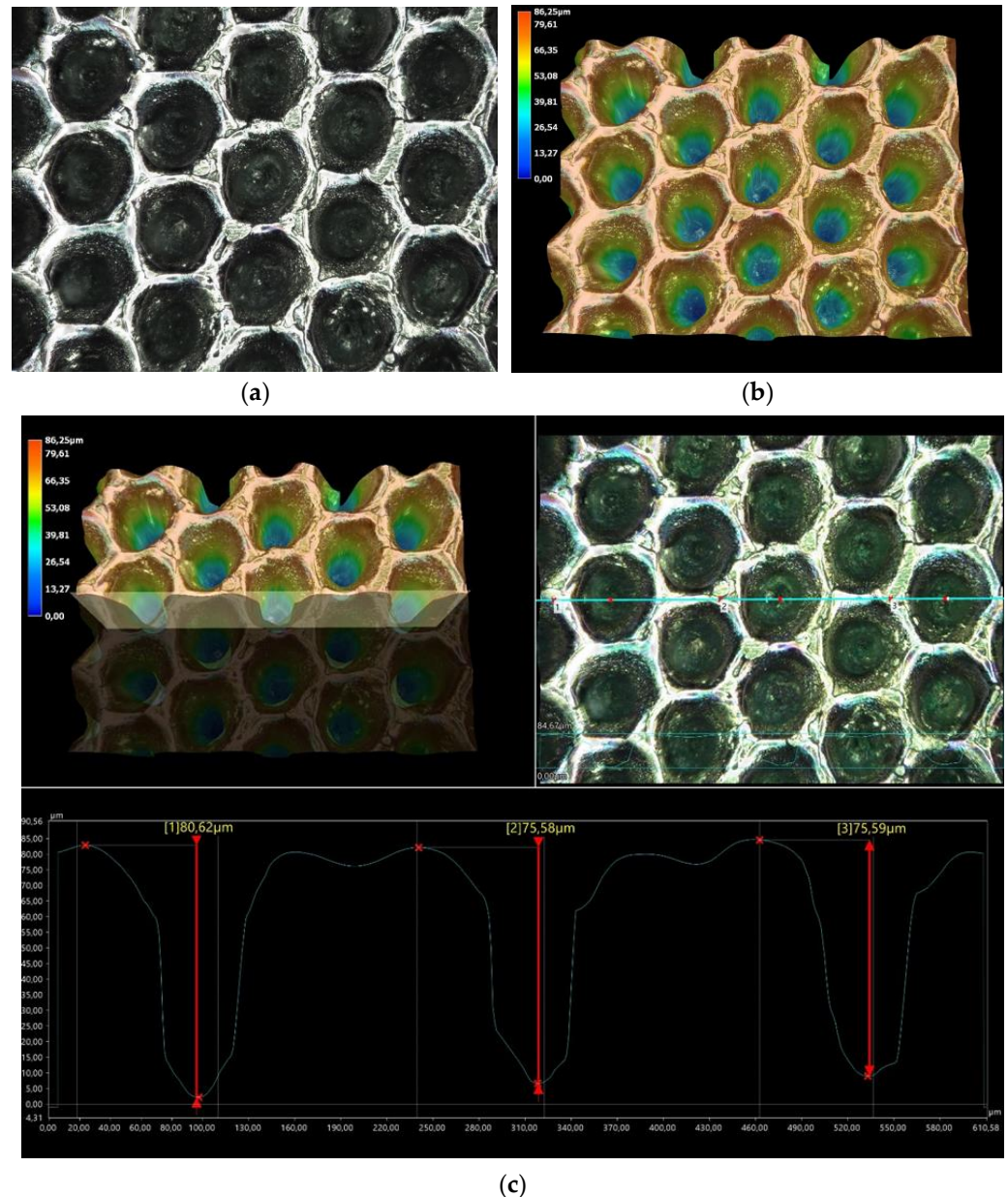


Figure 1. A set of microscopic images obtained during the assessment of dimensional properties of inkwells in an anilox roll (Roll 1—brand new): (a) 2D view; (b) 3D view; and (c) 3D view with measurement details.

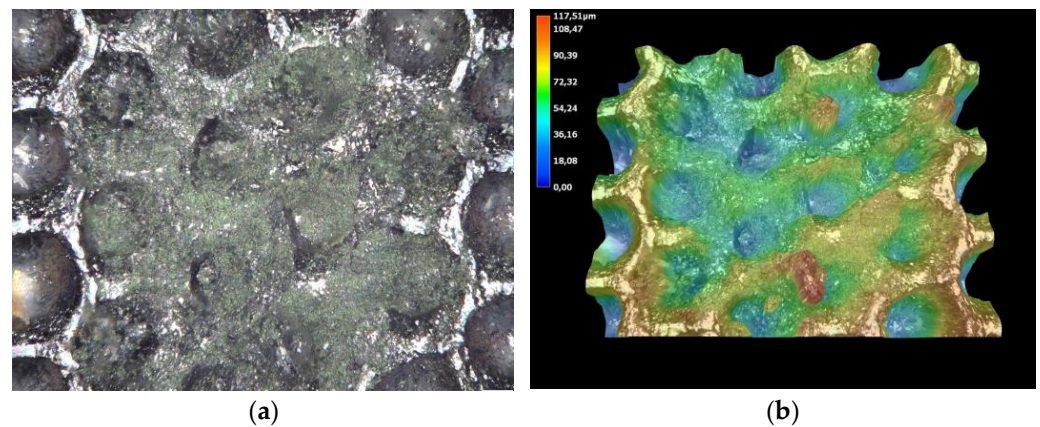


Figure 2. A set of microscopic images showing intentionally damaged areas on an anilox roll (Sample 4): (a) 2D view; (b) 3D view.

The results obtained from the microscopic measurements indicate that after the multi-printing process, the rolls lost approximately 20% of their ink capacity (Table 1 and Figures 1 and 2), resulting in a significant deterioration in ink transfer. For contaminated rolls, white spots were visible on the prints, and the color intensity on the printed material was noticeably lower.

Table 1. The fundamental parameters of the inkwells in the tested raster rollers.

Sample Number	Inkwell Depth [μm]	Inkwell Volume [μm^3]	Inkwell Area [μm]	Capacity [μm]
1 (brand new)	80.42 (3.39) *	331,500 (12,600)	25,520 (1010)	15.6 (0.6)
2 (undamaged, after printing)	62.9 (2.89)	285,090 (11,400)	24,860 (980)	12.5 (0.5)
3 (undamaged, printing, cleaning)	78.61 (2.97)	325,900 (14,800)	25,650 (1220)	15.4 (0.7)
4 (damaged, printing, cleaning)	77.26 (3.06)	330,500 (12,900)	25,010 (1130)	15.3 (0.6)
5 (damaged, printing, cleaning—water)	70.29 (3.86)	302,000 (17,600)	24,360 (860)	13.6 (0.8)

* Standard deviations are given in brackets.

The rolls numbered 3, 4, and 5 underwent a cleaning procedure using an ultrasonic cleaner. A cleaning agent designed specifically for anilox rolls was utilized for rolls 3 and 4, while roll number 5 was cleaned with distilled water.

Roll number 3, which represented an undamaged roll subjected to the printing and cleaning process, essentially restored its initial ink capacity (Figure 3). This indicates that utilizing an ultrasonic cleaner along with a suitably selected chemical agent enables the highly effective cleaning of the rolls.

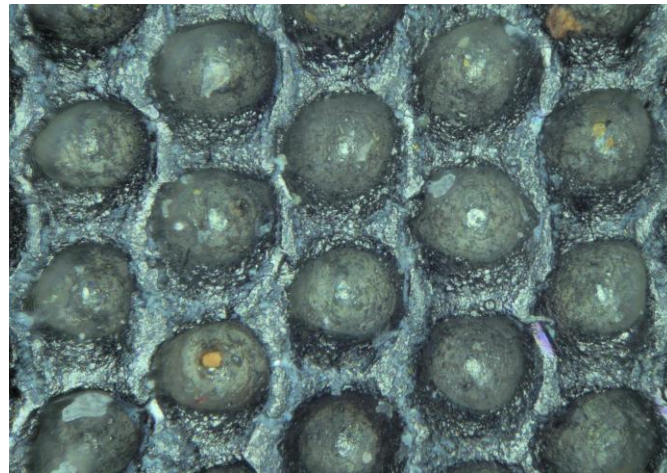


Figure 3. Surface of the undamaged anilox roll after a cleaning procedure using an ultrasonic cleaner.

For roll number 4, which had locally introduced damage, the undamaged surface of the roll appeared practically unchanged. Correspondingly, results concerning the depth, surface, and ink capacity of the inkwells were closely aligned (Table 1). Nevertheless, in areas where local damage occurred, significant impairments emerged following the cleaning procedure. These impairments directly indicated the complete delamination of the ceramic layer from the roll, as their depth exceeded the thickness of the ceramic layer stated by the manufacturer. This is illustrated in the microscopic images below (Figure 4).

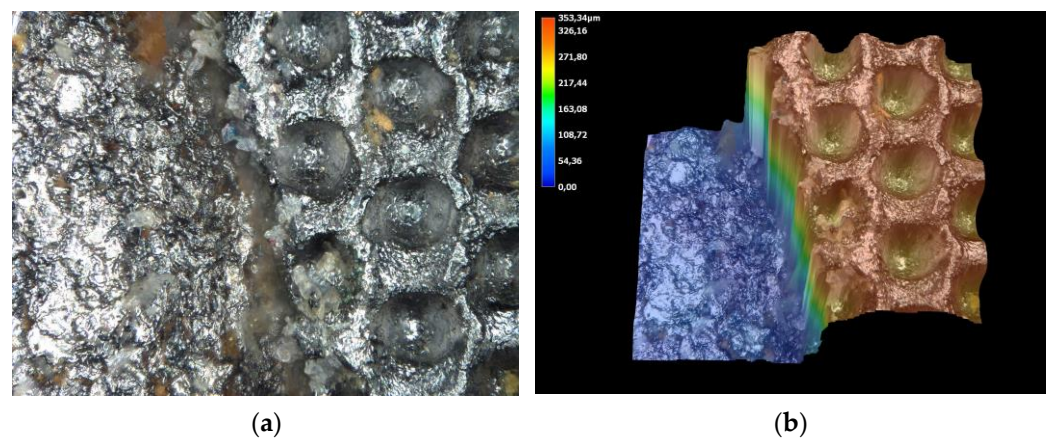


Figure 4. Surface of the damaged anilox roll after a cleaning procedure using an ultrasonic cleaner: (a) 2D view; (b) 3D view.

It should be noted that the depth of the damage exceeded 300 microns (precisely measured at 319 microns). These damages were observed in 4 out of the 12 areas with damage on the roll's surface.

Similar damages were also observed for roll number 5, which underwent the same cleaning procedure but using pure distilled water, without the addition of any cleaning agent.

4. Conclusions

The microscopic technique employed in this study is a highly effective method for assessing the condition of anilox rollers. It facilitates measurements on the screen of the threshold width, inkwell opening, capacity, and depth. Comparing images of the new and used anilox rolls after a certain operational period enables the observation that a decrease in inkwell depth (from 80.42 μm to 62.90 μm) and inkwell volume, from 331,500 μm^3

to 285,090 μm^3 , caused significant deteriorations in the inkwell performance and in the print quality.

The procedure of cleaning anilox rolls using an ultrasonic cleaner is rapid, efficient, and relatively straightforward. It enables the rolls to be cleaned and to attain over 98% of their initial ink volume (325,900 μm^3) and inkwell depth (78.61 μm), a fully satisfactory outcome. Furthermore, this procedure is safe for undamaged rolls. In the tested rolls that exhibited no damage, no changes were noted on the cell surface, suggesting an adverse effect on the ceramic surface of the rolls. However, for rolls with mechanical surface damage, the cleaning process in an ultrasonic cleaner can lead to a significant exacerbation of this damage, including the delamination of the ceramic coating, which, in this study, caused the full removal of the ceramic layer and partial layer of the core material, as the depth of the damage was significantly higher (353 μm) than the thickness of the ceramic layer (approximately 250 μm). During the tests, the influence of the cleaning agent was ruled out, as an increase in surface damage was observed for both the sample washed with the chemical agent and with distilled water. Thus, the escalation of damage and delamination of the ceramic layer was attributed to the vibrations produced by the ultrasonic cleaner.

In terms of the practical applications, raster rollers should not undergo cleaning procedures using ultrasonic cleaners if they exhibit significant wear or have even minor mechanical damages that would indicate damage to the ceramic coating. In such applications, alternative, less-invasive methods should be employed, such as laser cleaning, utilizing lasers with pulse powers of less than 50 mJ, which ensures relatively gentler laser-cleaning conditions.

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References

1. Flexographic Technical Association. *Flexographic Image Reproduction Specifications & Tolerances 7.0, FIRST 7.0 Kindle Edition*; Flexographic Technical Association: Bohemia, NY, USA, 2022.
2. Izdebska, J. 11-Flexographic printing. In *Printing on Polymers Fundamentals and Applications*; William Andrew Applied Science Publishers: Norwich, NY, USA, 2016; pp. 179–197. [CrossRef]
3. Flexography: Principles & Practices 6.0; Flexographic Technical Association. Available online: <https://www.flexography.org/training-resources/resource-library/flexography-principles-and-practices/> (accessed on 27 July 2023).
4. Hamblyn, A. Effect of Plate Characteristics on Ink Transfer in Flexographic Printing. Ph.D. Thesis, Swansea University, Swansea, UK, 2015.
5. Abusaq, Z.; Zahoor, S.; Habib, M.S.; Rehman, M.; Mahmood, J.; Kanan, M.; Mushtaq, R.T. Improving energy performance in flexographic printing process through lean and AI techniques: A case study. *Energies* **2023**, *16*, 1972. [CrossRef]
6. Joshi, A.V. Optimization of flexo process parameters to reduce the overall manufacturing cost. *Int. J. Optim. Control Theor. Appl.* **2022**, *12*, 66–78. [CrossRef]
7. The Secret to Print Consistency: Maintaining Anilox Roll Volume. Available online: <https://www.flexography.org/industry-news/print-consistency-maintain-anilox-roll-volume/> (accessed on 28 July 2023).
8. Döring, J.E.; De Schouepnikoff, L. Review on the art of anilox-manufacturing—From the coated cylinder up to the gravure. In *Proceedings of the Thermal Spray 2011: Proceedings from the International Thermal Spray Conference, Hamburg, Germany, 27–29 September 2011*; Volume 83713, pp. 542–549. [CrossRef]
9. Savickas, A.; Stonkus, R.; Jurkonis, E.; Iljin, I. Assessment of the condition of anilox rollers. *Coatings* **2021**, *11*, 1301. [CrossRef]

10. Damaged Anilox Rollers—How to Save On Repairs Case Study. Available online: <https://www.daetwyler-usa.com/daetwyler-value-of-expertise/> (accessed on 28 July 2023).
11. The problem of Scoring Lines on Anilox Rolls. Available online: <https://flexopedia.net/scoring-lines-on-anilox-rolls/> (accessed on 28 July 2023).
12. Anilox Scoring Prevention. Available online: <https://www.harperimage.com/AniloxRolls/Anilox-Guides/Anilox-Damage-Prevention> (accessed on 28 July 2023).
13. Scrubbing the Cells. Available online: <https://www.flexotechmag.com/key-articles/24074/scrubbing-the-cells/> (accessed on 28 July 2023).
14. Bould, D.C.; Hamblyn, S.M.; Gethin, D.T.; Claypole, T.C. Effect of impression pressure and anilox specification on solid and halftone density. *Proc. Inst. Mech. Eng. B J. Eng. Manuf.* **2011**, *225*, 699–709. [CrossRef]
15. Żółek-Tryznowska, Z. 6-Rheology of printing inks. *Print. Polym. Fundam. Appl.* **2016**, *87*–99. [CrossRef]
16. Anilox Selection: The Impact on Ink Strength, Drying & Curing. Available online: <https://www.flexography.org/industry-news/anilox-selection-ink-strength-drying-curing/> (accessed on 28 July 2023).
17. Saad, A.A.E.-R.E. Environmental Pollution Reduction by Using VOC-Free Water-Based Gravure Inks and Drying Them with a New Drying System Based on Dielectric Heating. Ph.D. Thesis, Bergische Universität Wuppertal, Wuppertal, Germany, 2007.
18. Savickas, A.; Stonkus, R.; Jurkonis, E. Investigation of anilox roller cell clogging. *J. Graph. Eng. Des.* **2021**, *11*, 61–67. [CrossRef]
19. Żółek-Tryznowska, Z.; Rombel, M.; Petriaszwili, G.; Dedijer, S.; Kašiković, N. Influence of some flexographic printing process conditions on the optical density and tonal value increase of overprinted plastic films. *Coatings* **2020**, *10*, 816. [CrossRef]
20. Instructions for the Cleaning and Care of Anilox Rollers. Available online: https://www.zecher.com/media/Zecher_Cleaning_and_Care_Anilox_Rollers.pdf (accessed on 30 July 2023).
21. Anilox Roll Cleaning. Available online: <https://www.drachchem.co.uk/anilox-roll-cleaning.php> (accessed on 30 July 2023).
22. Specifying the Right Anilox Roll. Available online: <https://www.harperimage.com/AniloxRolls/Anilox-Guides/Specifying-the-Right-Anilox-> (accessed on 30 July 2023).
23. Ultrasonic Tanks: Frequently Asked Questions. Cheshire Anilox Technology-Ultrasonic Tanks-FAQ. Available online: <https://cheshireanilox.co.uk/wp-content/uploads/2017/08/Ultrasonic-tanks-FAQ.pdf> (accessed on 30 July 2023).
24. 5 Methods of Anilox Roller Cleaning—Advantages and Disadvantages. Available online: <https://www.printsystems.pl/en/2016/11/29/5-methods-of-anilox-roller-cleaning/> (accessed on 30 July 2023).
25. Industry News. How to Clean Anilox Roller. Available online: <https://www.jctprinting.com/news/en/News-20181225-013243.html> (accessed on 30 July 2023).
26. Correct Use of Laser Cleaning for Anilox Rollers. Available online: <https://flexopedia.net/laser-cleaning-for-anilox-rollers/> (accessed on 30 July 2023).
27. Jin, H. *Use the Laser Engraving Machines to Achieve Laser Cleaning, Laser Post-Melting and Roughness Control of the Anilox Rolls*; Internship Report; Apex Europe B.V.: Hapert, The Netherlands, 2015.
28. Anilox Cleaning Systems. Available online: https://www.researchgate.net/publication/293631262_Anilox_cleaning_systems (accessed on 30 July 2023).
29. Anilox Development and the Need to Clean. Available online: https://www.researchgate.net/publication/296541896_Anilox_development_and_the_need_to_clean (accessed on 30 July 2023).
30. How to Clean Anilox Rolls & Understanding the Chemicals Involved, Flexographic Technical Association. Available online: <https://www.flexography.org/industry-news/how-to-clean-anilox-rolls-understanding-chemicals/> (accessed on 30 July 2023).
31. Ceramic Anilox Roll Care and Maintenance. Available online: https://www.praxairsurfacetchnologies.com/-/media/corporate/praxairsurface/us/documents/brochures/p9125_aniloxrollmaintenance_lr.pdf?la=en (accessed on 30 July 2023).
32. Anilox Cleaning Systems: Preserving Roll Life. Available online: <https://docplayer.net/20815633-Anilox-cleaning-systems-preserving-roll-life.html> (accessed on 30 July 2023).
33. Shape, Volume, Count: Standard Anilox Specifications in Flexographic Packaging. Available online: <https://www.flexography.org/industry-news/shape-volume-count-standard-anilox-specifications-in-flexographic-packaging/> (accessed on 30 July 2023).
34. Anilox Roll Specifications: Line Count or Volume? Available online: https://www.labelandnarrowweb.com/issues/2008-07/view_features/anilox-roll-specifications/ (accessed on 30 July 2023).
35. ISO 25178-1:2016; Geometrical Product Specifications (GPS)—Surface Texture: Areal-Part 1: Indication of Surface Texture. International Organization for Standardization: Geneva, Switzerland, 2016.

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