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Mottling in Production of Cardboard and in Offset Printing

ABSTRACT

White Lined Chipboard (WLC), made from wastepaper, is widely used for high-quality packaging applications that require consistent optical density and uniform tonal reproduction. A critical printing defect affecting visual appearance in multicolor offset printing is mottling—characterized by localized variations in ink transfer, uneven ink setting, and cloudy tonal reproduction in solid areas and halftone gradients. This study examines the relationship between wet-end process conditions, middle and print ply formation, baseboard structural uniformity, and offset printability on a 200,000 t/a recycled WLC machine (GD2, GD3 and GT2 grades). Non-uniform fiber distribution creates micro-scale variations in basis weight, porosity, coating holdout, and surface absorbency, which lead to uneven ink absorption during printing—particularly visible in fine screen rulings, light cyan/magenta tones, and smooth gradients. To mitigate mottling, a systematic wet-end optimization program was implemented, focusing on raw material fiber ratio adjustments (OCC and recovered paper blend), shake roll parameters, stock consistency control, and jet-to-wire speed ratio optimization to reduce local basis weight variations prior to blade coating. Process modifications were continuously evaluated in the laboratory using an IGT Amsterdam 2 printability tester to isolate water-interference mottling from back-trapping mottling. Findings were validated through commercial offset press trials operating at 10,000–12,000 sheets/hour. The results confirmed that wet-end formation improvements significantly reduced both laboratory-measured mottling indices and commercial print non-uniformities. The study demonstrates that resolving print mottling requires an integrated, process-oriented methodology connecting board machine wet-end control with laboratory printability simulation and commercial press validation.

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Recycled cardboard, board machine, formation, wet end optimization, mottling, white lined chipboard (WLC), GD2, GD3, offset printing, IGT Amsterdam 2

1. Introduction

Umka D.O.O. Umka is a board mill located close to Belgrade, on the riverbank of the Sava. It is a state-of-the-art facility for the production of WLC (White Line Chipboard). WLC is defined as a multilayer board (three layers – bottom, middle and print ply), characterized by a white colored coated print ply suitable for high-quality printing and converting. It is widely used for folding cartons and other packaging applications (food packaging, pharmaceutical, automotive, cosmetics, etc.).

The main raw material is recovered wastepaper, mostly collected in the Republic of Serbia. Umka is the biggest wastepaper recycling plant in Serbia and surrounding countries. At the moment, yearly production capacity is 200.000t, of finished product, divided into five qualities: Umka Color, Umka Pak, Umka Special, Umka brown back, Umka Liner. Since Umka is exporting more than 85% of its production to countries in the EU, most of the customers are high-end printing houses, with some of the most demanding end users (Lego, Dr Oetker...); expectations regarding the quality of the finished prod-

uct are getting bigger. The aim of this paper is to show the close connectivity of different parameters that are influencing the quality of the finished, printed product with regard to a specific quality characteristic – mottling.

2. Statement of the problem - mottling in WLC board production

WLC (White Lined Chipboard) is a multilayer cardboard that is commonly produced from different types of fibers, originating from recovered paper and cardboard, with individual layers differing in composition, purpose, and properties. For this type of paperboard, the quality of the printing surface depends not only on the final coating but also on the cardboard structure formed during the initial stages of the production process on the board machine. Mottling is a phenomenon characterized by visual non-uniformity in the printed image, manifested as local variations in optical density and color reproduction (Fahlcrantz & Johansson, 2004; Lee et al., 2021). In WLC cardboard production, this issue is particularly significant because the final coating, although it improves surface smoothness and print properties, cannot always fully compensate for irregularities originating in the structure of the baseboard.

Therefore, understanding mottling requires an analysis of the entire production process, starting with stock preparation and layer formation in the wet end of the machine, followed by the press section and drying, and continuing through calendaring, coating, and final printing. Particular attention is paid to the formation of the middle layer (filler ply) and the top layer intended for printing (print ply), as their properties directly affect the uniformity of the cardboard web and the performance of the print ply. The mottling effect in demanding print jobs can occur through several effects:

- **Fine screen ruling**

Mottling can be particularly noticeable when printing low and medium screen rulings, as these conditions require a carefully balanced interaction between the dampening solution and the ink on the printing plate. In halftone areas, the distribution and transfer of ink must remain stable to ensure consistent reproduction. Excessive dampening can disturb the ink–water balance, resulting in irregular ink transfer from the printing plate to the blanket and, consequently, a cloudy or mottled appearance in the printed image. In cardboard printing, non-uniform absorptiveness can further aggravate this problem. Small halftone dots may behave differently depending on the local surface properties of the substrate. In areas with higher or lower absorptiveness, dot deformation and dot gain may vary, resulting in uneven tonal reproduction. For example, a nominal 30% halftone may reach an apparent printed tone value of 40% in areas where ink spreading or other printing-related effects increase dot gain.

- **Smooth tonal gradients**

Smooth tonal gradients (ferlauf) involve a gradual change in tonal value and halftone dot size across the printed area. As with fine screen rulings, uniform substrate properties and stable printing conditions are essential for achieving smooth and consistent tonal transitions. Variations in paperboard absorptiveness may lead to local differences in ink transfer and dot gain, resulting in visible irregularities.

- **Light cyan and magenta tonal values**

Light cyan and magenta tones may be particularly susceptible to back-trapping mottling in multicolour offset printing. Cyan and magenta are often printed in the earlier printing units, depending on the selected ink sequence. Under certain conditions, the ink film transferred to the blanket may be partially disturbed by the subsequent printing unit. This phenomenon can occur when the tack and rheological properties of the inks, together with the condition of the ink film, cause the subsequent printing unit to partially pick off or disrupt the previously transferred ink film on the blanket. The resulting local variations in ink transfer can produce a mottled appearance, particularly in light halftone areas where even small changes in colour density are readily visible. The behaviour of black ink may differ because of differences in pigment characteristics, ink formulation, and its position in the printing sequence. However, the effect cannot be attributed solely to the strength of the black pigment; ink tack, ink sequence, trapping characteristics, and press settings must also be considered.

From the perspective of offset printing, mottling represents one of the most difficult printability defects because it is not visible before printing (multicolour) is finished and usually cannot be eliminated through conventional press adjustments. Increasing ink density, modifying fountain solution balance, changing printing pressure or adjusting blanket packing often produces limited improvements. Consequently, printers experience longer make-ready times, higher waste, and reduced production efficiency.

2.1. Formation – influence on print quality

WLC (White Lined Chipboard) is not a homogeneous material but a multilayer structure whose final properties result from the interaction between its individual layers. Each layer contributes specific mechanical, structural, and surface characteristics to the finished product. Consequently, print quality cannot be assessed solely based on coating properties; the structure of the cardboard beneath the coated surface must also be taken into consideration. The formation of the cardboard

web in the west end of the machine represents one of the key stages in determining print properties of WLC cardboard. During this stage, fibers suspended in water are distributed and bonded to form layers that subsequently acquire their final properties through pressing, drying, calendaring, coating and finishing. Formation quality depends on several interrelated factors, including the preparation and homogeneity of the stock, fiber characteristics, headbox operation, the relationship between jet velocity and machine speed and drainage conditions. Fiber orientation is also an important aspect of the formation process. Fibers may be distributed in different directions, and their degree of orientation influences certain mechanical and structural properties of the material (stiffness MD/CD). Changes in fiber orientation and local fiber distribution can have an effect on possible mottling appearance. The middle layer (filler ply) accounts for the largest proportion of the overall cardboard structure. Its formation influences fiber distribution, local basis weight, porosity, and the compactness of the cardboard web. If local variations in fiber concentration or distribution occur during formation, areas with different densities and different responses to calendaring and drying may develop. These variations can be transferred to the print ply and consequently, to the coating, thereby affecting the final surface structure, i.e. final print quality. The top layer intended for printing (print ply) plays a more direct role in determining surface properties. Its uniformity, fiber distribution and coating acceptance characteristics influence the extent to which a uniform cardboard surface can be achieved. If the print ply is insufficiently homogeneous, the coating may exhibit locally varying penetration into the substrate, uneven distribution and differences in its ability to form a smooth, uniform surface layer. Non-uniformity in the substrate may affect the uniformity of top-layer formation and subsequently contribute to variations in the cardboard surface during pressing, drying, and coating.

One of the key parameters is basis weight, which represents the mass of material per unit area and is expressed in g/m². In addition to the average basis weight, its local distribution is also important. Cardboard may have an acceptable average basis weight while still containing small areas with different local fiber concentrations. Such variations can affect local porosity, thickness and surface absorption. All this can lead to the appearance of mottling.

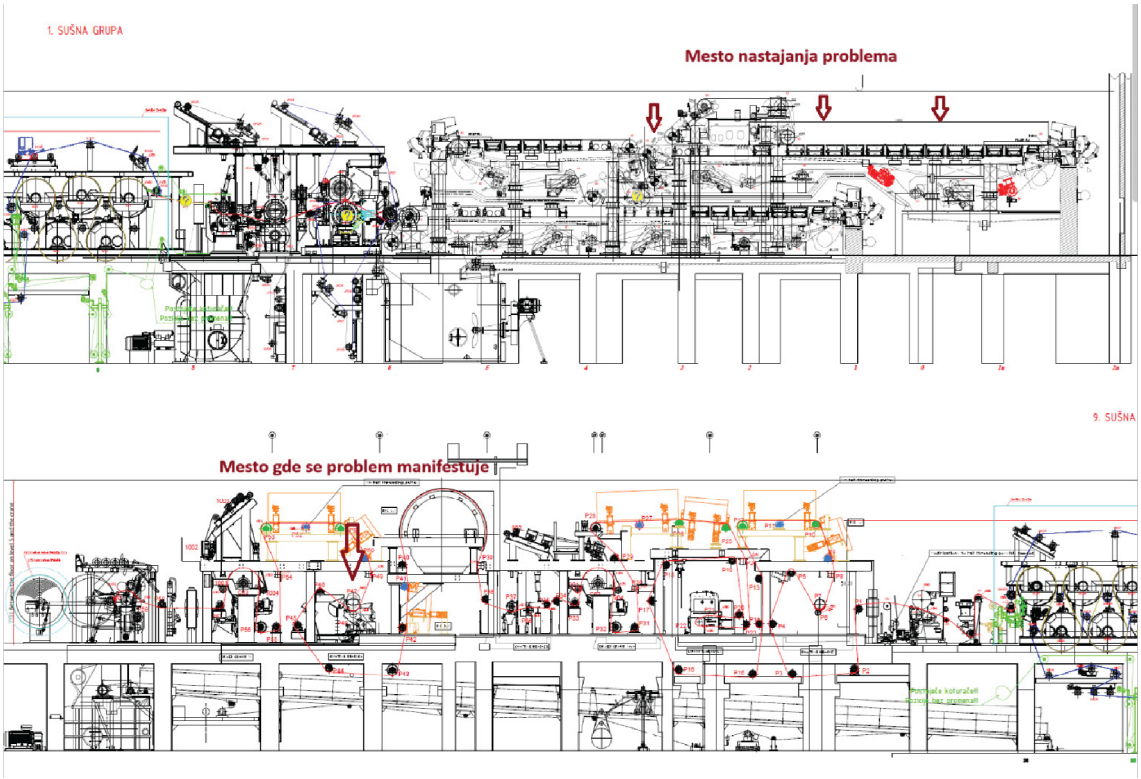
Porosity determines the extent to which the material structure contains interconnected or isolated pores through which, in the case of board production and coating formulations, penetration can occur. Depending on the size, distribution and connectivity of these pores, different areas of the cardboard may exhibit different behaviors during coating application and ink transfer (Karlovits, Lavrič & Nemeš, 2018). Surface absorption is also an important factor, as it influences the rate and extent to which the ink penetrates the material. If absorption varies across the surface, differences may occur in ink transfer, ink setting and the final optical appearance of the printed image.

The purpose of coating is to provide the appropriate smoothness, coverage, and surface properties required for high-quality printing (brightness). However, the coating's ability to form a uniform surface also depends on the properties of the base board, including its smoothness, porosity, absorptiveness and structural homogeneity (Rousu, Gane, Eklund, 2005; Preston, Nutbeem & Chapman, 2011). Consequently, defects in the underlying cardboard structure may be reflected in the final coated surface, even when the coating process parameters remain stable. It is particularly important to emphasize that mottling cannot be regarded solely as a surface defect originating during coating. Coating is one of the final stages in which the printing surface is formed. However, the properties of this surface depend mostly on the characteristics of the underlying substrate. If irregularities develop during the formation stage, subsequent processing operations may mitigate their effects, but they may not be able to eliminate them.

2.2. Wet end optimisation

Wet-end optimisation involves the adjustment of process parameters to achieve the most uniform fiber formation possible. In the context of mottling reduction, optimisation focuses on improving the formation of the middle and top plies, minimising local variations in fiber distribution and ensuring a more uniform substrate prior to coating application. Attention must also be given to the proportions of different recovered paper grades used during stock preparation. One of the fundamental prerequisites for process stability is the consistent dosing and thorough mixing of different raw materials. Recovered old corrugated containers (OCC) are used in the preparation of the middle ply. OCC typically contains relatively long fibers originating from corrugated packaging materials, which contribute to the stiffness and bonding potential of the resulting fiber network. Although these longer fibers promote inter-fiber bonding, their arrangement may leave voids within the fiber structure. These spaces can be partly filled by shorter fibers obtained from recovered coated cardboard, other suitable graphic paper grades and mixed recovered paper.

The purpose of incorporating these materials is not merely to modify the overall furnish composition, but also to achieve a more balanced distribution of long and short fibers. An appropriate combination of fiber lengths can contribute to a more uniform fiber network and improve the structural consistency of the paperboard. The resulting properties depend on the quality and condition of the recovered fibers, their relative proportions and the effectiveness of stock preparation.



» **Figure 1:** *The cardboard production machine setup in Umka board mill*

Following stock preparation, ply formation represents another critical stage in the production process. At this stage, stock consistency and the operating conditions of the shake roll in the middle-ply forming section should be evaluated together, as both may influence fiber distribution, inter-ply bonding, and the uniformity of the paperboard web. Their effects should be assessed in relation to the specific configuration and operating conditions of the board machine. The top ply determines surface smoothness and print quality, whereas the middle plies carry primary bulk. Properties of the middle ply, such as fiber type and density distribution, influence the through-thickness properties and overall stability of the top layer (Nygårds, 2022; Lindberg & Kulachenko, 2022). The relationship between stock consistency and formation quality is influenced by several interacting process variables, including drainage conditions, flow characteristics, and the operating parameters of the forming system.

In particular, lower stock consistency at the point of ply combination may promote more uniform formation of the baseboard and its surface. Under the operating conditions considered in this study, a minimum consistency of 9% is specified as a process constraint and should not be interpreted as a universally applicable threshold. The optimum value must be established according to the design of the forming section, the characteristics of the furnish and the required paperboard properties. From the perspective of print quality, wet-end optimisation should be considered an integral part of a comprehensive strategy for reducing mottling, rather than an isolated measure aimed solely at improving the final coated surface.

3. Materials and methods

Amsterdam 2, an instrument from Dutch company IGT (Figure 2.), is the main testing equipment for top ply, coating and mottling analysis. Tests are done multiple times during a shift – every change of grammage or quality.

The IGT Amsterdam 2 printability tester enables laboratory simulation of offset printing and assessment of the printing performance of cardboard. The instrument can be used to evaluate two types of mottling: water mottling and back-trapping mottling. While there are several other techniques to evaluate mottling from the printing perspective (Jurič et al., 2015), the IGT test methods are mainly used as an industry standard method in the paper and cardboard making industry.

These tests help distinguish between mottling associated with the absorptive properties of the cardboard substrate and mottling that may arise from interactions between successive ink films during multicolour printing.

The water mottling test simulates the interaction between the dampening solution and the cardboard surface during offset printing. In this procedure, water is applied to the paperboard using a dedicated dampening roller, simulating the action of the dampening system and the presence of water on the printing plate in an offset printing press. The purpose of this test is to determine whether the substrate itself contributes to mottling under controlled laboratory conditions.



» **Figure 2:** *IGT Amsterdam 2 lab testing device*

The back-trapping mottling test is particularly relevant when the water mottling test shows no significant mottling, but the customer experiences mottling during production printing. In such cases, the investigation can be extended to assess whether interactions between successive ink films, including their rheological properties and tack, contribute to the observed defect (Lee et al., 2021). The resulting print is evaluated for local variations in colour reproduction and uniformity. If mottling occurs under these conditions despite satisfactory results in the water mottling test, the findings may indicate that ink–ink interactions or other printing-process variables contribute to the defect, rather than substrate absorptiveness alone. However, this interpretation should be confirmed by considering the actual printing conditions, ink properties, and press settings (Ozaki, Bousfield & Shaler, 2008; Kim, Pollock & Wittbrodt, 1997).

The IGT Amsterdam 2 enables multiple cardboard samples to be tested within a short period, with individual tests typically completed within approximately 30 minutes, depending on the test configuration and procedure. This facilitates the comparative assessment of samples produced under different manufacturing conditions or obtained from different production batches. By combining water mottling and back-trapping mottling assessments, the laboratory method provides a practical means of distinguishing between different potential mechanisms responsible for mottling. The results can support root-cause investigations, guide corrective actions in paperboard manufacturing and printing, and contribute to improved print quality in WLC applications.

4. Experimental part – test printing

Laboratory testing and simulation play a key role in quality control; however, their true value can only be established under actual production conditions. Customer trials, conducted under commercial offset printing conditions, provide the final validation of whether laboratory-derived parameters reliably predict the behavior of paperboard on multicolour printing presses. For customer printing trials, paperboard samples are selected from the same production batches previously assessed using the IGT Amsterdam 2 printability tester. The selection includes samples for which testing has confirmed stable printing performance, as well as samples, where available, for which a potential risk of mottling has been identified. Using samples from the same production batches enables a more reliable comparison between laboratory findings and performance under commercial printing conditions. It also helps establish whether the observed differences in print uniformity are associated with paperboard characteristics or with variations in the printing process.

Although laboratory conditions cannot be fully replicated in a commercial printing environment, the customer trial is conducted under controlled and documented press conditions to ensure reliable comparisons.

The main printing parameters to be monitored include:

- Constant printing speed: 10,000–12,000 sheets per hour, where compatible with the press configuration and job requirements.

- Printing pressure: cylinder pressure and impression settings adjusted according to the paperboard's basis weight, calliper and press specifications.
- Dampening solution: controlled dosage and pH, with particular attention to their influence on ink–water balance and their relevance to the laboratory water mottling assessment.
- Ink application and colour density: stable ink supply and monitoring of printed colour density using a densitometer or spectrophotometer on the colour control strip

4.1. Ink sequence and back-trapping assessment

On a multicolour offset press, the standard ink sequence is monitored and documented. Depending on the press configuration and printing requirements, a sequence such as K–C–M–Y (black, cyan, magenta, yellow) may be used. Particular attention is given to the interaction between successive ink films, especially where magenta and yellow are printed over previously deposited cyan. Under certain conditions, differences in ink tack, rheological properties and trapping behaviour may disturb the previously transferred ink film on the blanket. This can result in local variations in colour density and a mottled appearance. The trial therefore assesses whether the back-trapping effects observed during laboratory testing can also be identified under commercial printing conditions.

Once the press has reached stable operating conditions, printed sheets are collected at defined intervals, for example, after every 500 or 1,000 impressions. Sampling intervals should remain consistent throughout the trial and should cover the relevant stages of the production run.

4.2. Instrumental assessment

These results are compared with the quantitative measurements obtained from the IGT Amsterdam 2 system, including high-resolution image-analysis data was supported by the instrument's configuration. Because laboratory and commercial systems may use different measurement principles, the comparison should be based on appropriately defined and validated indicators rather than assuming direct numerical equivalence.

4.3. Visual assessment under standardized illumination

Printing operator and quality-control personnel visually inspect critical printed areas under standardised viewing conditions. Attention is on large solid areas, light cyan and magenta, midtone regions and smooth tonal gradients, where variations in print uniformity may be visible. The visual assessment determines whether mottling observed during laboratory testing is also apparent in the commercial print and whether its location and visual characteristics are consistent with the laboratory findings. By combining instrumental measurements with visual evaluation, the customer trial establishes a practical correlation between laboratory printability results and actual press performance. This approach supports the identification of the dominant mottling mechanism and helps determine whether corrective actions should focus on paperboard manufacture, ink formulation, press settings, or a combination of these factors.

5. Conclusions

Mottling is a print-quality defect that becomes visible during offset printing, but may originate from variations in the structure and surface properties of WLC paperboard. The formation of the middle ply (filler ply) and the top ply (print ply) is particularly important, as it influences substrate uniformity, absorptiveness and the performance of the coated surface. Also, influence on appearance of mottling during offset printing (high-end quality) can be a result of processes on the printing machine. To minimise mottling, a systematic optimisation program was implemented in the mill, on the board machine, i.e. on the wet end. Process adjustments focused primarily on improving middle and print ply formation at the wet end, jet-to-wire ratio and formation uniformity. These measures aimed to reduce local variations in fiber orientation before applying coating. Wet-end optimisation, including control of furnish composition, stock preparation, and ply formation, offers opportunities to minimise structural variations and reduce the risk of mottling.

The successful implementation of process modifications was continuously evaluated using the IGT Amsterdam 2 printability tester, which enabled laboratory simulation of offset printing under controlled conditions. Standardised mottling test prints were produced on samples collected during production, allowing objective comparison of print uniformity. The laboratory results were correlated with commercial offset printing trials and demonstrated that improvements in formation resulted in measurable reductions in mottling intensity and more stable ink transfer. The IGT Amsterdam 2 printability tester enabled controlled laboratory assessment of water and back-trapping mottling, while commercial printing trials establish whether laboratory findings reflect actual press performance. Effective mottling reduction therefore requires an integrated, process-oriented approach, beginning with wet-end optimisation at the board machine and extending through laboratory evaluation to validation under commercial printing conditions. This approach supports more reliable identification of defect mechanisms and helps determine whether corrective measures should focus on cardboard, printing parameters or both.

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