Retrospective on Microcell Surface Engineering for White Ink Transfer Efficiency

Marek Skrzynski

Abstract

White represents 40% to 50% of the total cost of ink used. For decades, flexographic printers have struggled with persistent white-ink mottle and pinholing, which compromised solid coverage, print quality, and press efficiency (Miraclon, 2022; E.C. Shaw, 2019; Skrzynski, 2014, 2015). To mitigate these issues, many resorted to screening solids with high tonal values (97–98%) and fine halftone rulings (150–200 lpi) in place of solids. These workarounds often sacrificed opacity, increased workflow complexity, and provided only partial and inconsistent relief (Harper, 2015; Skrzynski, 2015).

The introduction of microcell surface patterns on photopolymer flexo plates opened a new frontier. By engineering microscopic geometries into the plate surface, printers altered ink-wetting behavior, improving ink laydown uniformity, reducing pinhole density, and increasing opacity at lower ink volumes (Miraclon, 2022; E.C. Shaw, 2019; Skrzynski, 2014). Initially targeted at process CMYK inks, these techniques soon proved beneficial for white inks and spot applications (Miraclon, 2022; Skrzynski, 2014). Early solutions, such as Kodak's NX dimpled-dot architecture, were less effective against white-ink or spot color mottle due to large pigment particle sizes and ink rheology diverging from ideal conditions (Harper, 2015; Skrzynski, 2015).

This paper presents a retrospective review of microcell development combining historical observations, previously published investigations, and controlled experimental work performed using modern imaging systems, multiple microcell technologies, and several anilox configurations. The objective was to evaluate performance improvements achieved and to correlate opacity measurements (OP), mottle metrics, anilox volume (BCM), and pigment particle (nm scale) to specific microcell sizes (in pixels) and geometries. Experimental work performed at the Flexo Xperience Center (FXC) in Atlanta, combined with historical production observations and previously published commercial investigations (Miraclon, 2022; E.C. Shaw, 2019; Skrzynski, 2015), demonstrates that

CSW Inc., Ludlow, MA

optimized microcell structures can significantly improve white ink transfer efficiency while reducing required ink volume.

Results indicate that certain microcell and anilox combinations reduced required anilox volume by more than 30% while maintaining or improving opacity and substantially reducing mottle (pinholing). The findings further suggest that effective white ink transfer is governed not only by volumetric ink delivery but also by the interaction among pigment particle size, microcell geometry, wetting behavior, and surface energy.

Finally, the paper proposes future research directions extending beyond two-dimensional microcell geometry toward quantification of cells three-dimensional, volumetric parameters (BCM), as related to ink transfer volume and laydown efficiency.

Introduction

Flexography (Flexo) today is a high-speed, rotary-style relief printing process using flexible photopolymer plates to transfer ink onto diverse, often non-porous substrates. As printing method, Flexo has evolved from a relatively coarse reproduction method into one of the dominant technologies for packaging production. Over nearly a century, every major component of the process, including presses, inks, anilox rolls, imaging systems, and photopolymer plates, has undergone significant development. While flexography remains fundamentally mechanical in nature, many of its modern advancements originate from chemistry, optics, laser imaging, software, and computational screening technologies (Esko, 2025; E.C. Shaw, 2019).

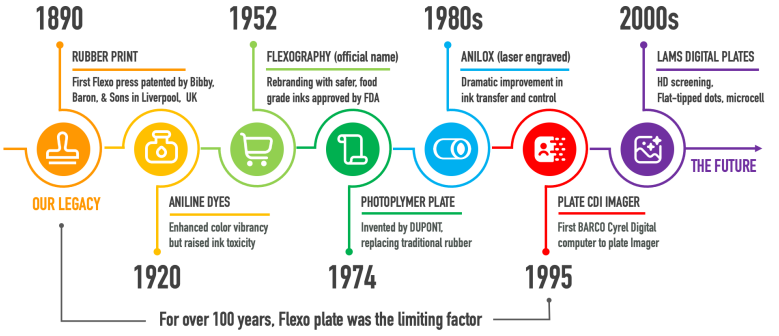


Figure 1: Historical development of flexographic printing

Among these advancements, photopolymer plate imaging and surface engineering have had a particularly strong influence on print quality and ink transfer behavior. Digital imaging workflows enabled the creation of increasingly sophisticated microstructures capable of manipulating fluid transfer at microscopic scale (Esko, 2025; Miraclon, 2022). The introduction of flat-top dot technologies, high-resolution imaging systems, and engineered microcell surface patterns significantly improved solid ink density, highlight reproduction, and laydown uniformity while reducing common defects such as pinholing (Esko, 2013; Miraclon, 2022). Modern micro-patterning approaches now allow flexographic plates to actively influence ink transfer behavior, functioning not only as image carriers but also as engineered fluid-control surfaces. Despite these improvements, white ink remains one of the most difficult and expensive applications in flexographic printing. White ink commonly accounts for approximately 65% of total ink usage and nearly half of total ink cost in many transparent flexible packaging applications due to the high concentration of titanium dioxide (TiO_2) pigments required to achieve acceptable opacity (Skrzynski, 2014; Harper, 2015). Rising TiO_2 costs, combined with increasing sustainability pressures, have intensified the need for improved transfer efficiency and reduced ink consumption.

Historically, flexographic printers attempted to improve white laydown by increasing anilox volume, doubling the ink layer, utilizing softer plate materials, modifying mounting tape compressibility, or replacing solids with screened tonal values. While these methods occasionally improved appearance, they frequently introduced secondary problems including reduced opacity, longer drying times, slower press speeds, and inconsistent print stability (Harper, 2015; Skrzynski, 2015).

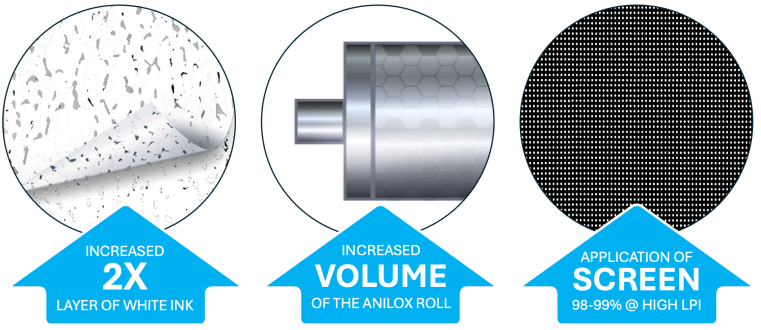


Figure 2: Historical White Ink Printability Workarounds

At the same time, flexographic white ink transfer presents unique rheological and particle-size-related challenges. Titanium dioxide (TiO_2) pigments used in white

inks are substantially larger and less finely dispersed than the pigments typically used in process CMYK inks, significantly influencing transfer efficiency, wetting behavior, and film formation dynamics. The larger particle morphology increases the likelihood of incomplete ink coalescence, uneven laydown, and pinholing, particularly on low-surface-energy film substrates. Consequently, microcell structures originally optimized for process-color applications did not always produce optimal results when applied to white ink systems, where pigment size, ink rheology, and volumetric transfer behavior differ considerably from conventional CMYK conditions (Miraclon, 2022; Skrzynski, 2015). The development of engineered microcell surface structures represented a significant shift in approach. Instead of relying exclusively on increased volumetric delivery, these technologies attempted to improve how ink spreads, wets, and transfers between interfaces. By modifying plate surface geometry at micron-level scale, printers gained the ability to manipulate ink behavior directly at the transfer interface.

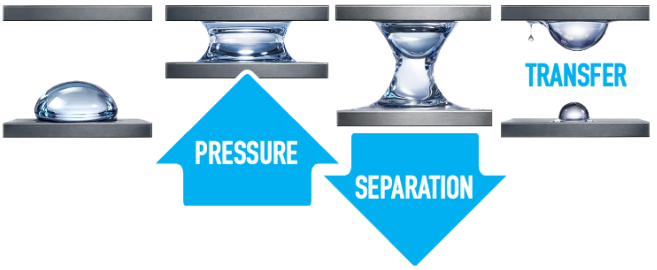


Figure 3: Idealized Ink Transfer Equilibrium Between Adhesion and Cohesion Forces in Flexographic Printing

Background and Theory

Ink Transfer Mechanism in Flexography

Ink transfer in flexography occurs through a sequence of interfaces: anilox → plate → substrate (Figure 4). At each stage, transfer efficiency is governed by the balance between adhesion and cohesion forces. Ink transfers successfully only when adhesion to the receiving surface exceeds both its internal cohesion and its adhesion to the previous surface (Figure 3).

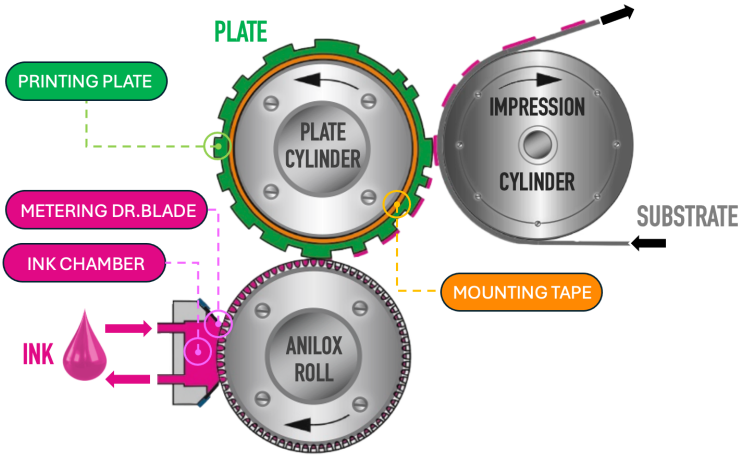


Figure 4: Diagram showing flexographic ink transfer system.

- A commonly cited rule-of-thumb within flexographic printing suggests that approximately 50%–80% of the ink volume contained in the anilox cells is transferred to the printing plate, while only 40%–70% of that transferred volume subsequently reaches the substrate (FlexoExchange, 2008; Cork Industries, n.d.). As a result, the effective substrate transfer may represent only approximately 20%–45% of the original engraved cell volume, depending on ink, surface energy, plate characteristics, and press conditions.
- In white ink applications, this transfer inefficiency is particularly pronounced due to the high titanium dioxide (TiO_2) pigment loading, larger particle size, and more complex rheological behavior. Historically, printers compensated for these limitations by utilizing higher-volume anilox engravings, typically in the range of 7–9 BCM and in some, cases even higher.

Role of the Anilox Roll

Anilox rolls have remained the central metering component of flexographic ink delivery since the 1940s, when mechanically engraved copper rolls replaced earlier transfer methods. The introduction of ceramic coatings and laser engraving technologies significantly improved durability, engraving precision, and ink release consistency (Harper, 2015; E.C. Shaw, 2019). Early engravings relied on relatively coarse four-wall diamond geometries near 200–300 LPI before the industry largely transitioned to 60° hexagonal closed-cell structures during the

1990s. As print quality demands increased, elongated and channel-based "slalom" geometries were introduced to improve ink flow, reduce turbulence and plugging, and enhance transfer consistency (Apex, 2023). At the same time, engraving resolutions increased from approximately 300 LPI to modern systems exceeding 1500 LPI, enabling thinner ink films, improved detail reproduction, and more precise ink transfer control (Harper, 2015; Apex, 2023).

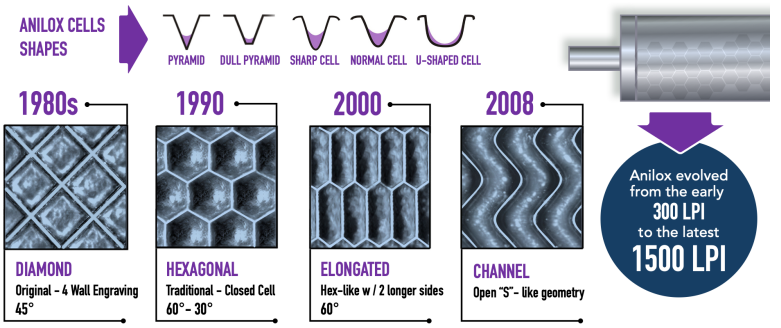


Figure 5. Evolution of anilox rolls engraving geometry.

Photopolymer Plate Surface Print Properties

The transition from molded rubber plates to photopolymer materials represented one of the most significant technological shifts in modern flexography. Traditional rubber plates featured a rougher and more porous surface structure that provided strong ink-carrying capability, particularly for large solids, coatings, and low-surface-energy film substrates. However, they lacked dimensional stability, imaging precision, and fine-detail reproduction. The introduction of digital photopolymer plates significantly improved imaging resolution, tonal reproduction, and print consistency, enabling flexography to compete with offset and gravure quality levels (DuPont, 2019). At the same time, the smoother and less porous photopolymer surface reduced natural ink-carrying and wetting behavior in heavy solid applications, particularly with white inks. As a result, laser-engraved elastomer materials continue to be used in specialized coating and high-opacity white ink applications where their rougher surface morphology can still improve ink release and transfer behavior under certain conditions (MacDermid, 2021; DuPont, 2019).

Role of Pigment Particle Size in Ink Behavior

White inks contain titanium dioxide (TiO_2) pigment particles that are significantly larger than the pigments typically used in process CMYK inks. While conventional process pigments commonly exist in the approximate range of

0.064–0.072 µm (64–72 nm), TiO_2 particles used in flexographic white inks are generally dispersed within the range of approximately 0.2–0.4 µm (200–400 nm), depending on the ink formulation, opacity target, and grinding process (Sun Chemical, 2022; Siegwerk, 2021).

Typical Pigment Type	Pigment Category	Particle Size Range	Approx. Size (nm)	Common Use in Flexo Printing
Phthalocyanine Blue / Green	Organic Pigments	0.01–0.08 µm	10–80 nm	Process Cyan
Quinacridone	Organic Pigments	0.02–0.10 µm	20–100 nm	Magenta, Violet
Diarylide / Azo Yellow	Organic Pigments	0.03–0.10 µm	30–100 nm	Process Yellow
Furnace Black	Carbon Black	0.01–0.05 µm	10–50 nm	Process Black
Titanium Dioxide (TiO_2)	Inorganic Pigments	0.20–0.40 µm	200–400 nm	White
TiO_2 Agglomerates	Inorganic Pigments	0.10–1.00 µm	100–1000 nm	High-Opacity White
Aluminum, Bronze / Copper Flake	Metallic Pigments	5–20 µm	5000–20000 nm	Metallic Effects (Silver, Gold)
Pearlescent / Mica-Based Pigments	Effect Pigments	5–25 µm	5000–25000 nm	Specialty Coatings and Effects

Table.1 Typical Particle Size Ranges of Common Pigments Used in Flexographic Printing Inks

This substantial difference in particle size directly influences ink transfer behavior, film formation, and surface wetting characteristics during the printing process (Figure 6). The larger TiO_2 particles increase the likelihood of incomplete film coalescence, pinholing, and uneven laydown, particularly when transferred through fine anilox engravings onto smooth photopolymer surfaces. In addition, larger pigment particles can become mechanically constrained within shallow or tightly packed engraving geometries, reducing effective ink release and transfer efficiency. Effective ink transfer in flexographic printing depends on a complex interaction among volumetric ink delivery, ink rheology and pigment morphology, anilox cell geometry, plate surface topology, and substrate surface energy. Equally important are the microscopic interactions occurring between pigment particle size distribution, anilox cell dimensions, and plate surface roughness, all of which influence ink release efficiency, wetting behavior, film continuity, and the formation of uniform ink laydown.

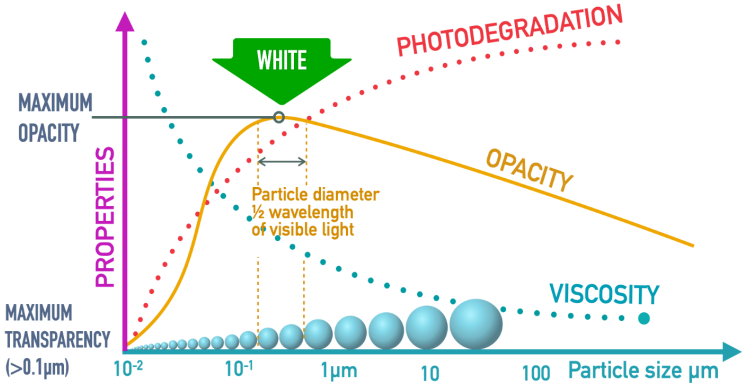


Figure 6: Relationship between pigment particle size and selected ink performance properties

Microcell Surface Engineering

The introduction of microcell surface engineering represented a major shift in how flexographic printers approached solid ink transfer optimization. Prior to its development, printers commonly attempted to improve ink laydown and reduce pinholing by screening solids with very high tonal values (typically 97–98%) rendered at fine line screens between 150–200 lpi. While these approaches occasionally improved visual smoothness, they often reduced opacity, increased workflow complexity, and produced inconsistent results (Skrzynski, 2015; Harper, 2015).

A significant breakthrough occurred in the late 2000s with the introduction of Kodak's FLEXCEL NX technology (currently Miraclon) and its DigiCap NX surface patterning system, which utilized controlled pixel-based micro-patterns to manipulate ink transfer behavior at microscopic scale (Miraclon, 2022).

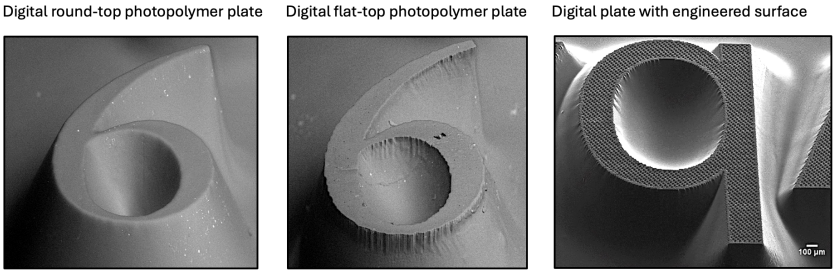


Figure 7. SEM images showing various forms of digital flexographic plate imaging and exposure methods.

This early success of surface patterning methods, followed by the introduction of special barrier built in the plate by Macdermid around 2014, capable of minimizing oxygen inhibition without the need for external exposure hardware, accelerated industry-wide development of similar microcell technologies. Other plate and imaging manufacturers rapidly expanded into a broad range of geometries, frequencies (Figure 8), and application-specific surface structures optimized today for process colors, spot colours, coatings, and particularly demanding white ink applications.

At the same time, the broader flexographic industry continued advancing digitally imaged photopolymer systems. The transition from analog film-based workflows to direct laser ablation of carbon LAM (Laser Ablative Mask) layers significantly improved imaging precision, tonal reproduction, and repeatability. However, early digital plates still produced round-top dot structures due to oxygen inhibition during UV exposure, limiting their ability to create stable microscopic

surface textures. The later introduction of oxygen-barrier technologies, including film laminations such as MacDermid LUX, inert-gas exposure systems such as DuPont Cyrel DigiFlow, and high-energy UV exposure systems such as Cortron enabled the formation of flat-top dot structures (Figure 6), with improved ink transfer consistency, higher solid densities, and greater press stability (MacDermid, 2021; DuPont, 2019).

Modern high-resolution flexographic imaging systems can produce extremely small and repeatable surface structures with near 1:1 translation between digital 1-bit TIFF image data (or ESKO's proprietary LEN files), the laser-imaged film emulsion or laser-ablated LAM mask, and the resulting photopolymer microstructures measured in microns on the final plate surface.

Advances in laser optics, imaging resolution, and UV exposure control have significantly improved the fidelity between digital pixel geometry and the physical microcell structures formed during platemaking, enabling highly controlled and repeatable surface-engineering strategies for ink transfer optimization (Esko, 2025; Miraclon, 2022).

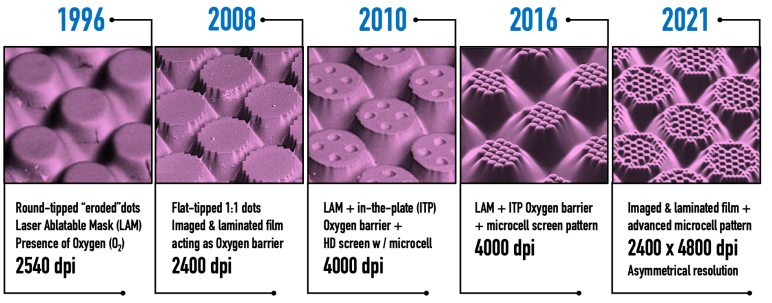


Figure 8: Progression of digital flexographic plate imaging and microcell surface engineering

Historical Background of Earlier White Ink Research

In 2014, CSW, Inc., alongside Dave Recchia, Sr. Printing Process Specialist, and Brian Cook Sr. Application Specialist from MacDermid Graphic Solutions R&D department, initiated a collaborative effort focused on optimizing the entire flexographic white ink delivery system. The objective was to maximize opacity, reduce pinholing, and improve laydown uniformity while maintaining high-speed single-pass production capability (Skrzynski, 2014, 2015).

A major advancement during this work was the introduction of measurement systems capable of quantifying surface defects. Technologies such as FlexPRO, developed by Lukas Pescoller at PERET (Pescoller, L., & Hahlweg, C. 2013).,

enabled pinholing and mottle to be transformed from subjective visual observations into measurable numerical data. For the first time, defect severity could be quantified, compared, and correlated against press variables, yielding significantly deeper insight into white ink transfer behavior (Figure 9).

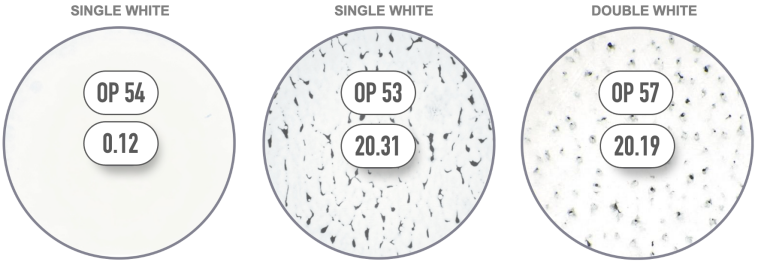


Figure 9: Correlation between measured Opacity (OP) / Mottle, and visual appearance of white ink laydown

At the 2014 FTA Annual Conference, preliminary findings from this collaborative research were presented, documenting both the prevalence of white ink transfer defects and potential paths toward improvement (Skrzynski, 2014). The work demonstrated that white ink performance depended on the interaction among multiple press and plate parameters rather than a single variable alone.

WHITE PLATE MATRIX

SURFACE PATTERN	INK OPACITY						MOTTLE FACTOR						PLATE DUROMETER	ANILOX LPI
	MOUNTING TAPE DENSITY													
	SOFT	MED	HARD	SOFT	MED	HARD	SOFT	MED	HARD	SOFT	MED	HARD		
	NO TEXTURE			SURF. TEXTURE			NO TEXTURE			SURF. TEXTURE				
NONE	52.6	53.7	53.3	53.2	54.1	53.9	25.5	18.6	15.7	21.0	11.6	9.3	SOFT	250
	52.4	54.1	54.4	52.0	53.3	54.2	31.5	21.1	20.9	28.5	25.8	18.2	MEDIUM	
	53.5	54.7	53.5	52.8	53.8	54.2	30.0	18.3	15.3	27.3	17.0	15.5	HARD	
	49.9	51.5	51.7	50.7	52.2	53.1	28.2	19.9	11.9	22.0	11.6	7.0	SOFT	360
	49.0	50.9	51.0	49.4	50.8	51.1	36.0	26.3	28.9	37.2	29.8	25.9	MEDIUM	
	49.6	50.6	51.2	48.6	49.9	49.8	32.9	29.4	24.1	30.7	22.9	25.4	HARD	
3x3	52.6	54.1	53.8	56.3	56.0	56.3	26.7	17.8	15.4	8.8	1.6	0.8	SOFT	250
	53.0	54.6	55.2	54.9	55.3	56.0	26.1	21.0	16.7	13.8	12.7	9.0	MEDIUM	
	55.0	55.4	54.4	55.8	55.4	55.7	24.9	16.8	15.2	18.6	8.9	6.0	HARD	
	50.3	52.6	53.2	53.4	53.8	54.6	28.9	20.1	11.7	2.0	1.8	0.7	SOFT	360
	49.0	52.3	51.4	52.7	52.1	53.0	37.0	20.6	25.2	14.3	18.7	17.0	MEDIUM	
	49.8	50.9	51.4	52.5	52.8	51.5	34.2	27.0	25.3	8.6	10.3	5.0	HARD	

Figure 10: “White Plate Matrix” from early research showing 270 combinations of white transfer components that were studied.

The optimized configuration:

- plate durometer,
- engineered surface texture,
- micro-pattern frequency,
- mounting tape density,
- anilox geometry and volume,
- and controlled ink rheology

The research and resulting observations were further documented in two FLEXO Magazine articles: *The White Ink Matrix* (Skrzynski, 2014) and *Holes in Our Expanding World – Numerical Evaluation of White Ink Impact on ECG Printing* (Skrzynski, 2015). These publications explored the economic impact of white ink inefficiency and the importance of quantifying pinholing and mottle, particularly in Expanded Color Gamut (ECG) workflows where white ink uniformity directly affects overprinting color appearance and saturation.

These investigations also marked a shift away from purely volumetric approaches toward engineering photopolymer plate surfaces to actively influence ink distribution and wetting behavior at microscopic scale. Early experiments utilizing simple low-frequency 3×3-pixel microstructures demonstrated that controlled surface geometry could significantly improve white ink transfer behavior, establishing an early foundation for later high-definition microcell technologies and modern surface-engineered flexographic plate systems (Miraclon, 2022; Esko, 2025).

Test Setup and Methods

Testing conducted in September 2023 at the FXC Atlanta use an 8-colors SOMA CI flexographic press operating at 1000 ft/min under production-like conditions decks were configured to run white inks exclusively (Figure 11), enabling simultaneous evaluation of multiple anilox and microcell combinations. Standard- and high-opacity white inks with different titanium dioxide (TiO_2) loading levels were tested across multiple anilox technologies and volume configurations to evaluate the interaction between ink formulation, anilox geometry, and plate surface engineering.

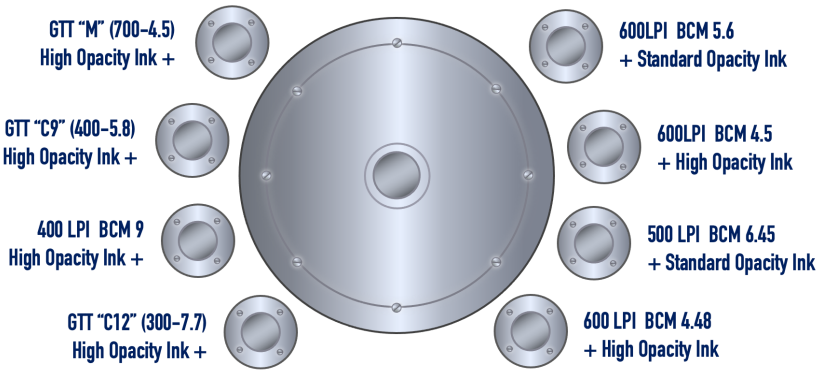


Figure 11. Schematic of CI press configuration with assigned 8 aniloxes and ink types used for the test.

Materials

- Substrate: reversed printed 1.5 mil (38 µm) BOPP film (38 dynes/cm)
- Plate: XSYS ITP 60 photopolymer (60 durometer, 0.067" thickness)
- Inks: solvent-based
    - Sun Chemical Standard Opacity White
    - Sun Chemical High Opacity White (higher TiO_2 loading)

Anilox Configurations

Multiple anilox rolls manufactured by Harper, Sandon and Apex were used, including:

- Harper 600 LPI @ 4.5 & 600 LPI @ 5.6 BCM both traditional 60°, hex engravings
- Sandon 500 LPI @ 6.45 & 600 LPI @ 4.48 BCM both traditional 60° hex engravings
- Apex GTT variants M (eq.700 LPI @ 4.5BCM), C9 (eq.400LPI-450 @5.8BCM), C12 (eq.300LPI @ 7.7 BCM) all open-channel engravings.

All anilox rolls used in the study were evaluated using Micro Dynamics 3DQC interferometric measurement systems and MicroScan3 software to ensure accurate BCM characterization and repeatable quality control measurements throughout testing (Micro Dynamics, 2025).

Microcell Structures

The number of microcell geometries available today is nearly 30 times greater than it was a decade ago, adding significant complexity to testing and comparison. Modern microstructures now vary not only in size and frequency, but also in symmetry, directional or bi-directional orientation, edge-support characteristics, and overall geometry. Our goal was not to optimize each individual combination, but rather to benchmark general performance trends under consistent press conditions and imaging settings.

Three major microcell technology groups were tested:

- ESKO
- Hamillroad
- HYBRID

Miraclon's solution was not included in this study due to the proprietary plate material and processing technology, to which the researchers did not have access. However, relevant published findings and observations are referenced where applicable.

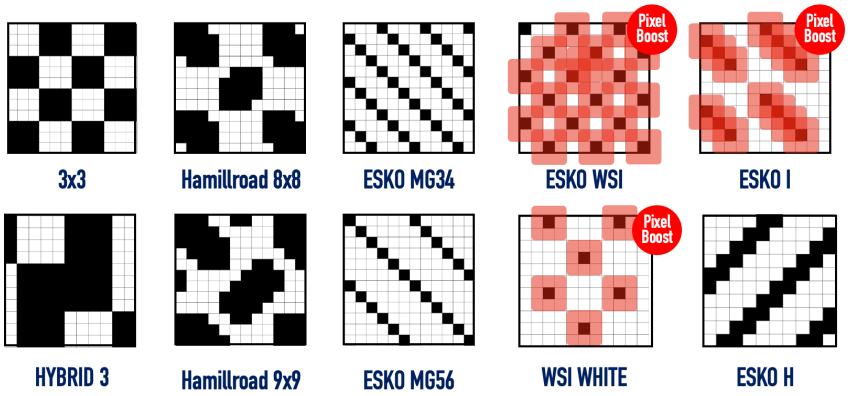


Figure 12: Examples of various microcell sizes and geometries used in the test.

- Each included multiple geometries and frequencies are listed later in the following Table 2.
- The growing complexity of modern microcell technologies is further amplified by imaging variables such as Pixel Boosting, where additional laser energy is used to enhance formation of 1pixel size structures during plate imaging. Improper boost calibration can significantly alter the original geometry, size, symmetry, and transfer behavior of the pattern, potentially affecting ink laydown consistency and edge definition (Esko,

2022; DuPont, 2023). As a result, identical microcell designs may perform differently depending on imaging conditions, plate material, and exposure technology, adding another layer of complexity to comparative evaluation.

- Other than Pixel Boosting applied to selected ESKO and Hamillroad single-pixel-cell patterns, no individual pattern optimization was performed. (Figure 11).
- All patterns were imaged utilizing ESKO Crystal CDI at 4000 dpi with XPS UV LED exposure and sized confirmed by measurement done with PERET FlexPRO3 (PERET, 2023).

Measurement Methods

- Opacity (OP): Measured using X-Rite eXact spectrophotometer (white and black backing)
    - Scale: 0 (transparent) to 100 (opaque)
- Mottle Index: Measured using PERET FlexPRO3 (PERET, 2023).
    - Values <1 indicate near-perfect uniformity.
    - Values ~20 – 30 represent typical legacy defects.

Each test condition was sampled approximately ten times throughout the duration of the press run, collected at the beginning, middle, and end of the run to capture potential variability associated with press stabilization, ink transfer consistency, and extended production behavior.

Results

The Performance Matrix shown in Table 2 compares all tested microcell geometries across multiple anilox configurations, engraving technologies, and white ink formulations using averaged opacity and mottle measurements. The matrix was designed to visualize the relationship among microcell geometry, anilox volume, engraving structure, and white ink transfer behavior. Heat Map color coding was applied relative to the untreated baseline plate without microcell surface modification. Dark green indicates the highest-performing combinations with increased opacity and minimal mottle or pinholing, while red identifies conditions performing below baseline expectations. Yellow and orange indicate partial or moderate improvement relative to the control condition.

Anilox / Ink	HI Opacity - Sandon 600 / 4.48		HI Opacity - Harper 600 / 4.5		HI Opacity - Apex GTT-M		Standard - Harper 400 / 6.6		Standard - Sandon 600 / 6.45		Standard - Apex GTT-C9		Pattern Maker
Baseline	49.5	23.53	52.1	19.01	49	21.22	49.8	11.09	51.4	10.57	51	10.55	
Pattern	Opacity (%)	Mottle	Opacity (%)	Mottle	Opacity (%)	Mottle	Opacity (%)	Mottle	Opacity (%)	Mottle	Opacity (%)	Mottle	
ESKO													
Screen I	53.6	1.68	54.6	0.49	51.1	3.68	51.1	0.96	53.3	0.66	52.5	0.53	
Screen H	53.7	4.03	54.7	0.7	50.9	2.33	50.4	0.4	53.3	0.32	52.8	0.3	
Screen F	51.1	11.53	53.5	5.38	47.6	13.51	50.2	0.21	53.3	0.15	51.9	0.41	
Screen D	36.3	36.08	45.4	26.23	35.1	44.34	47.7	5.5	51.3	1.55	48.8	3.25	
Screen C	31.2	44.55	42.5	30.88	30.6	52.36	45.3	13.63	50.7	4.2	44.9	14.89	
Screen B	25.6	56.99	39.6	37.57	25.4	55.45	40.9	27.02	49.4	3.76	42.9	25.27	
MG56	52.9	15.29	54.5	5.51	53	3.07	50.9	1.67	52.6	1.43	52.3	0.8	
WSI White	45.3	17.56	53.2	2.98	49.2	10.67	50.9	0.97	53.5	0.36	52.5	0.11	
HAMILLROAD													
MC511	54.6	0.43	55.1		53	0.56	51.5	0.74	53.4	0.57	52.7	0.44	
DSP 9x9 2s	52.3	9.9	54.3	2.89	53	1.68	51.9	0.7	53.1	0.85	52.3	0.78	
DSP 9x9 1s	53.2	4.38	54.7	0.87	51.9	3.19	51.4	0.25	53.6	0.46	52.3	1.07	
DSP 8x8 2s	52.5	6.29	54.7	4.99	52.6	1.09	51.7	0.62	52.7	1.03	52.2	0.69	
DSP 8x8 1s	52.2	2.66	54.3	1.12	51.2	0.56	50.4	0.62	53.6	0.66	52.3	0.3	
DSP 7x7 2s	52.7	12.25	54.6	2.26	52.5	2.42	51.5	0.41	52.9	1.04	52.1	0.51	
DSP 7x7 1s	53.4	3.06	54.1	0.55	51.9	3	51.5	1.27	53.3	0.22	52.1	0.52	
DSP 5x5 2s	52.9	8.93	54.7	1.37	52.7	0.95	51.7	0.34	53.2	0.71	52.4	0.44	
DSP 5x5 1s	53	2.22	54.7	0.75	51.7	0.98	51.5	0.82	53.1	0.78	52.4	0.56	
HYBRID													
W-3-2	48.6	20.36	53.3	16.85	50	17.25	51.8	1.61	52	2.84	52.1	0.4	
Pattern 6	50.8	12.23	54.9	2.61	45.9	13.92	52.5	0.15	53.5	1.12	52.8	0.3	
Pattern 9	49.9	15.26	54.5	5.54	50.9	4.89	50.9	2.82	52	3.69	52.2	1.79	
Pattern 4	52.6	0.81	55.1	0.34	51.8	0.81	52.5	0.25	52.9	0.35	52.5	0.44	
S-2-2	52.2	12.96	54.6	2.96	52	4.49	51.9	0.94	52.8	0.8	52.4	0.49	
WC-2-4	50.4	16.85	54.7	7.63	50.7	5.93	50.4	4.93	51.9	3.72	51.6	7.95	
Pattern 8	43.1	20.07	55	2.85	43.9	20.32	51.3	0.23	52.9	0.88	51	1.11	
Pattern 3	52.9	5.51	54.8	6.13	53.1	1.03	51.4	0.75	52.8	0.92	52.3	0.19	
White 5	38.4	46.64	42.5	36.51	39	41.1	47.6	10.94	50.5	2.25	46.2	20.21	
W-5-2	49.7	22.28	51.6	21.67	50.3	18.23	50.7	4.86	51.6	4.09	51.9	3.11	
Pattern 7	50.2	17.42	52.1	12.62	50.1	7.32	51.3	4.94	53	2.4	52	5.37	
Pattern 5	49.7	17.01	52.3	10.07	49.4	9.52	49	0.67	51.3	0.22	50.1	1.87	
White 4	49.2	22.5	51.3	12.25	46	22.26	49.5	2.86	51.2	2.87	50	3.71	
White 3	51.1	17.04	53.4	2.92	48.8	12.59	50.1	8.27	52.3	3.24	51.2	6.78	
White 2	47.3	22.94	51	12.48	46.3	10.87	50.8	1.65	52.2	1.19	51.4	2	
White 1	48.3	21.64	53.8	3.44	51.2	5.42	48.1	7.94	51.1	3.77	48.8	4.34	

Table 2: Heatmap performance matrix of opacity and mottle results

Key Observations

- Certain microcell geometries significantly improved both opacity and ink laydown uniformity, confirming that plate surface engineering can improve white ink transfer beyond what is achievable with an untreated solid plate.
- The results challenge the long-standing assumption that higher anilox volume alone is the primary path to improved white opacity. Several lower-BCM configurations produced equal or better opacity with substantially lower mottle when paired with certain microcell structures.
- In white ink application, increasing anilox volume alone produced diminishing returns. Higher-volume configurations did not consistently deliver the best combination of opacity and mottle reduction, particularly when compared with lower-volume aniloxes paired with optimized microcell surface structures. In one comparison, increasing anilox volume by approximately 15% resulted in only about a 1.5% increase in measured opacity, highlighting the limited efficiency of volume-driven optimization alone.
- Reductions in anilox volume exceeding 30% (from 7.7 BCM to 4.5 BCM) appear possible without a major impact on opacity, creating a direct opportunity for more sustainable and cost effective TiO_2 consumption. In some cases, lower-volume aniloxes also produced lower pinholing and more uniformed ink laydown.

- Microcell geometry selection is critical. Some patterns produced substantial improvement, while others performed worse than the untreated baseline. The interaction between microcell size and TiO_2 particle size is critical and need to be study further. Structures that are too large or too small relative to pigment dimensions can degrade performance.
- Certain lower-frequency or more open microstructures appeared more tolerant to variations in ink formulation and anilox configuration, while finer or denser patterns often showed greater sensitivity to process conditions and imaging variables.
- Directional and channel-based microstructures may influence ink flow and release differently than symmetrical or isotropic patterns, suggesting that orientation and fluid-path geometry could play a role in transfer behavior and pinholing reduction. Perhaps subject of another study.
- While performance varied across all tested technologies and configurations, Hamillroad patterns demonstrated the broadest and most consistent improvements across a wider range of ink and anilox conditions. Other evaluated microcell systems also produced significant gains in selected applications, although results tended to be more dependent on specific pattern geometry, ink formulation, and anilox configuration.
- Every microcell technology supplier represented in the matrix had at least one pattern that significantly improved performance over the untreated baseline.
- The best-performing combinations were generally those that balanced opacity improvement with mottle reduction, rather than those that maximized opacity alone.
- Mottle reduction was often a more sensitive indicator of surface-engineering effectiveness than opacity alone. Some samples showed acceptable opacity but poor uniformity, reinforcing that opacity cannot be used as the only quality metric for white ink laydown.
- The strongest results suggest that effective white ink transfer is governed by the interaction between plate surface topology, anilox release behavior, ink rheology, and pigment particle size and not by ink volume alone.
- Variability between seemingly similar microcell geometries indicates that small differences in pattern depth, spacing, or imaging fidelity may significantly influence final transfer performance.

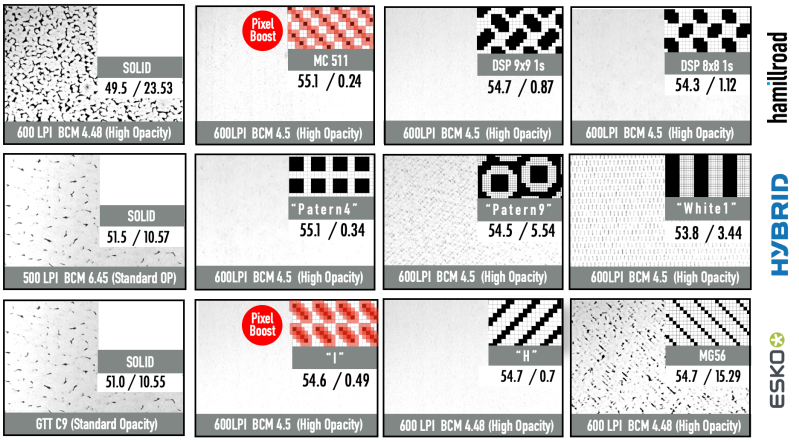


Figure 13: Visual and numerical correlation between microcell geometry and white ink laydown performance

- A similar trend is seen with MIRACLON surface technology: the right combination of cell geometry and anilox volume improves ink laydown while reducing ink consumption. Although mottle index data isn't available for direct comparison, the published images suggest relatively low mottle levels.

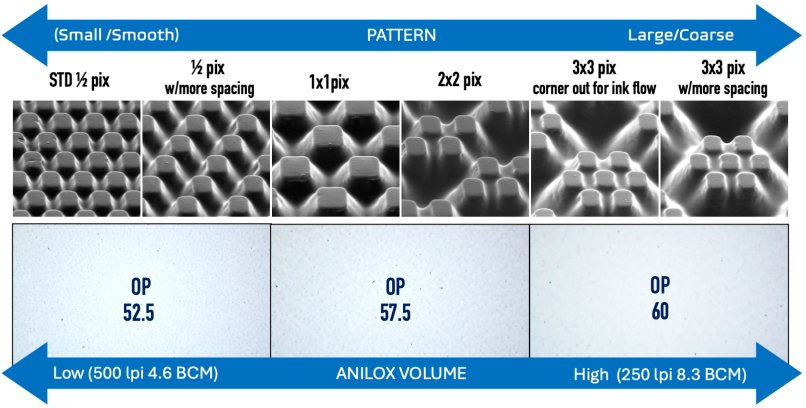


Figure 14: A correlation between Miraclon's microcell geometry and white ink laydown quality

Summary

- Our results challenge the long-standing flexographic industry assumption that improved white ink performance can be achieved

primarily through increased ink volume and higher BCM anilox engravings. While traditional practice historically favored larger cell volumes to compensate for poor opacity and uneven laydown, the results demonstrate that volumetric delivery alone does not guarantee improved transfer efficiency. In numerous cases, lower-volume engravings combined with optimized microcell surface geometries produced superior opacity, smoother laydown, and significantly reduced pinholing compared to conventional higher-BCM configurations. The data strongly suggest that white ink transfer efficiency is governed less by absolute ink volume and more by the complex interaction among microcell topology, pigment particle size, ink rheology, wetting behavior, and anilox release dynamics.

Future Work

Future research should examine the relationship between plate surface engineering, anilox volume, and resulting ink laydown performance. While current studies focus primarily on two-dimensional microcell geometry and frequency, emerging 3D measurement methods could allow microcell characteristics such as surface geometry, depth, and volume to be evaluated similarly to BCM measurements used for anilox rolls. This approach would help quantify how microcell volume, pigment particle size, and anilox volume interact during ink transfer between the anilox, plate, and substrate, while also supporting development of predictive models for optimizing flexographic print performance. A proposed methodology includes:

- introducing BCM-equivalent measurements as a third axis within the microcell performance matrix,
- evaluating the interaction between cell geometry, cell volume, and resulting ink laydown behavior,
- quantifying volumetric transfer efficiency and its relationship to opacity, mottle reduction, and print consistency.

The broader objective is to better understand microcell behavior and its interaction with mono- and multi-pigment ink formulations, while developing more predictive and repeatable surface-engineering strategies. Longer term, such work could support a more standardized framework for microcell engineering across the flexographic industry, similar to how line screen (LPI), screen angle, or anilox BCM values are specified today. An industry-wide database correlating ink formulation, pigment size, rheology, substrate characteristics, and optimal microcell geometries could help improve predictability, reduce trial-and-error optimization, and contribute to more consistent flexographic workflows.

Acknowledgment

The author acknowledges Dave Recchia and Brian Cook for early research collaboration in white ink transfer and microcell surface engineering; Lukas Pescoller for support in quantitative mottle analysis; Garrett Taylor and the SOMA team, together with Becky Bunch from the Flexo Xperience Center, for support during the 2023 testing; Esther Hollekamp for research assistance and data organization. The author also thanks Dr. John Anderson for insights into Miraclon technology and, together with Robert Miller, for their peer review of this paper. Special thanks are extended to CSW, Inc. for its continued support of flexographic research and for providing the resources that made this and other R&D initiatives possible.

References:

Esko. (2013). *Pixel+ Surface Patterning Technology for Flexographic Plate Imaging.* https://www.esko.com/en/products/flexo-engine/flexo-screening

Esko. (2025). *CDI Quartz, Market-Leading Flexo Print Quality*. https://www.esko.com/en/products/cdi-quartz

Miraclon – Pick the Right Pattern for Flexo Platemaking. (2022). https://www.miraclon.com/flexo-know-how/your-pattern-your-productivity/

DuPont – Opacity, Mottle, Graininess. (2019). https://www.dupont.com/October-2019.pdf

E.C. Shaw Company – Flexographic Plate Technology. (2019). https://ecshaw.com/plate-technology/

Harper Corporation – Anilox Engraving for Flexographic Printing . (2015). https://harpercorporation.com/anilox-engraving-flexo-magazine-june-2015/

Marek Skrzynski –The White Ink Matrix. FLEXO Magazine. (2014). https://www.flexography.org/flexo-magazine/the-white-ink-matrix/

Marek Skrzynski –Holes in Our Expanding World – Numerical Evaluation of White Ink Impact on ECG Printing. FLEXO Magazine. (2015) https://www.flexography.org/flexo-magazine/holes-in-our-expanding-world/

Miraclon – Back to Basics: How to Select the Correct Pattern and Trial for Results. Huey, M. (2021). https://www.miraclon.com/content/uploads/2021/10/Back-to-Basics-How-to-Select-the-Correct-Pattern-For-You_10.11.21_Final.pdf

FTA – Controlling Ink Spread with Advanced Surface Patterning for Flexography. (2021). https://www.flexography.org/industry-news/controlling-ink-spread-with-advanced-surface-patterning-for-flexography/

Hamillroad Toolkit – Bellissima DMS and ECG Printing. (2024). https://forum.flexography.org/wp-content/uploads/2024/03/HamillroadSoftware-20532606_Hamillroad_Toolkit_Final_-_Proof_1_2.pdf

MacDermid Graphics Solutions. (2021). *LUX Flat Top Dot Technology for Advanced Flexographic Printing.* https://graphics.macdermid.com/products/lux/

Miraclon – Optimized Platemaking Solutions for Flexo Printing. (2024). https://www.miraclon.com/content/uploads/2024/05/EN_Portfolio_brch_US_pages_250116_LR.pdf

Hamillroad Bellissima DMS Technical Overview. (2023). https://infoflex.flexography.org/wp-content/uploads/2023/02/Hamillroad-Software-download-INFOFLEX-2023.pdf

PERET GmbH – FLEX4PRO Flexo Plate Analyzer. (2023). FLEX4PRO Flexo Plate Analyzer and Print Analysis System. https://www.peret.it/products/flexo-prepress/flex3pro?id=275

Pescoller, L., & Hahlweg, C. (2013). Inspection and Characterization of Flexo-Printing Plates. https://www.researchgate.net/publication/260850019_Inspection_and_characterization_of_flexo-printing_plates

MicroDynamics LLC. (2025). *Anilox Volume Measurement and Flexographic Quality Control Systems.* https://www.microdynamics.info

Sun Chemical. (2013). *Sun Chemical Launches SolarFlex Neutron White UV Flexographic Ink.* https://www.labelsandlabeling.com/news/inks-coatings/sun-chemical-launches-solarflex-neutron-white-uv-flexographic-ink

Sun Chemical. (2022). *Flexographic Ink Troubleshooting App.* https://inktsa.sunchemical.com/flexographic/

Siegwerk. (2021). *Inks & Coatings for Flexible Packaging.* https://www.siegwerk.com/en/company/what-we-do/flexible-packaging.html

Siegwerk. (2021). *Flexographic Printing Troubleshooting Guide.* https://www.siegwerk.com/en/services/consulting/flexographic-printing-guide.html, https://www.siegwerk.com/en/media/news/white-ink-performance-packaging-printing.html

Apex International. (2023). *APEX GTT 2.0 Consistent Flexoprinting.* https://www.apexinternational.com/apex-academy/apex-gtt-2-0-consistent-flexoprinting/

HYBRID Software. (2025). *Intelligent Flexo – Surface Screening Solution for Flexo.* https://hybridsoftware.com/products/intelligent-flexo/