Effects of Paper Properties on Color Gamut of Dry-Toner Electrophotography

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Abstract

The graphic communications industry has seen rapid growth of applications of digital printing presses due to higher demands of short-run or print-on-demand and variable data printing jobs. One of the major digital printing technologies used for production printing is dry-toner electrophotography (EP). Compared to traditional printing presses, it is also easier and quicker for digital presses to make changes in color management, especially with inline measurement systems.

In this study, a Konica Minolta AccurioPress C2070 at Ball State University was used to study the effects of paper properties on color gamut. An inline IQ-501 Intelligent Quality Optimizer installed on the press along with EFI Fiery™ Color Profiler Suite was used to create color profiles for seven paper substrates, four coated and three uncoated. The G7 method was used for calibration, and then 1,617 patches (CGATS IT8.7/4) were printed and measured inline to create ICC profiles, which were evaluated and compared in CHROMiX ColorThink™ Pro. Paper structural and optical properties such as roughness, permeability, color, gloss, whiteness, yellowness, brightness, etc. were measured, and their effects on color gamut were studied.

It was found that paper optical properties affected the color gamut of EP more than structural properties. Achieving a higher gamut volume of EP requires a paper with lower yellowness index and whiteness index, a* and b* (or chroma) closer to 0, less OBA content, and lower permeability.

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Introduction

Digital presses have become one of the most efficient ways to create short-run or personalized print products. Their ability to operate without physical image carriers makes them particularly well-suited for on-demand publishing and short run production. Additionally, digital presses offer advantage of low maintenance, requiring less frequent cleaning and servicing than traditional systems. They also provide reliable and consistent output with minimal downtime, making them a practical choice for streamlined operations. Another key benefit is their compatibility with a wide range of substrates, including both paper and synthetic materials, which enhances their versatility in diverse printing applications.

Compared to traditional printing presses, it is also easier and quicker for digital presses to make changes in color management, especially with inline measurement systems. Thanks to integrated inline color management systems, digital presses can not only perform automated registration and real-time color density adjustments, but also create custom ICC profiles for different substrates under different environmental and press conditions [1] [2].

In this study, a dry-toner EP press with an inline measurement system was utilized to print a variety of papers with different structural and optical characteristics. The objectives were to evaluate and compare the resulting color gamuts, assess how paper properties influence color gamut performance, and provide informed substrate recommendations for optimal results in dry-toner EP printing.

Experimental Procedure

Paper Substrates

A total of seven different paper substrates from different manufacturers were used in this study, four coated and three uncoated, as listed in Table 1. Their basis weights range from 90 g/m^2 to 270 g/m^2.

Brand	***Manufacture***	***Type***	***Weight (g/m^2)***
Tango Digital Cover	WestRock	Coated	195
Everyday Digital	Mohawk	Coated	270
Sterling Gloss Cover	Verso	Coated	216
Kromekote Gloss Cover	CPI Paper	Coated	170
Platinum Digital	Navigator	Uncoated	90
Bold Digital	Xerox	Uncoated	105
Cougar Text	Domtar	Uncoated	118

Table 1: Specifications of the paper substrates used in the study

Paper Testing

Thickness was determined using a digital thickness gauge (TMI). Roughness was measured using a Parker Print-Surf (PPS) testing device (TMI), with a clamping pressure of 1000 kPa using soft backing. Permeance was measured using the same PPS device with a clamping pressure of 1000 kPa. Permeability coefficient was calculated using Equation (1), where K represents the permeability coefficient (μm²), Q is the Parker Print Surf flow rate (mL/min), and L is the paper thickness (m) [3].

$$K = 0.048838 \, x \, Q \, x \, L \qquad (1)$$

Gloss was measured at a 75° angle using a GM247 glossmeter (Technidyne). CIE L*a*b* values were measured using a spectrophotometer (Techkon SpectroDens), with values representing lightness (L*), the red-green spectrum (a*), and the blue-yellow spectrum (b*). Measurement conditions were D50 illuminant, 2° observer's angle, and 0/45 geometry. Measurement mode was M1. Whiteness index and yellowness index were measured using the same spectrophotometer. Whiteness was set according to E 313, and yellowness was set according to D 1925. Values for "white" paper typically range between 90 and 120. A higher value indicates a "whiter" (brighter) appearance [4]. The use of artificial optical brightening agents (OBA) in a paper can also result in elevated values. A positive value for yellowness signifies that the paper has a yellow cast, while a negative value indicates a blue cast. Brightness was measured using the same spectrophotometer with TAPPI 452 setting. Similar to whiteness, paper brightness measures the amount of light reflected from a paper. However, unlike whiteness, which considers all wavelengths in the spectrum, brightness specifically focuses on a narrow range of blue light. A higher brightness value indicates greater light reflection. While brightness is an important factor in assessing a paper's appearance, it does not account for shade and whiteness, meaning two sheets with the same brightness level can still look significantly different. Some papers can achieve a brightness rating above 100 due to the presence of OBA. OBA was checked using the same spectrophotometer by applying measurement conditions M1 and M2, which involve testing with and without UV light stimulation. The final measurement result can be determined by the difference between the two CIE b* values. The amount of OBA can be evaluated based on ΔB (ISO 15397) and categorized according to ISO 12647-2 as follows:

- $0 \leq \Delta B < 1$: No OBA
- $0 \leq \Delta B < 4$: Faint OBA
- $4 \leq \Delta B < 8$: Low OBA

Profiling Process

A dry-toner EP press, Konica Minolta AccurioPress C2070, at Ball State University was used in this study. An inline IQ-501 Intelligent Quality Optimizer has been installed on the press, which includes a spectrophotometer to measure the front side, and two scanners, one for the front side and one for the back side [1]. The printing process control software was EFI Fiery™ Command Station 6.8, while the color management software was EFI Fiery™ Color Profiler Suite 5.0.

ICC profiles were created using the following steps:

1. CMYK calibration: After 10 warmup pages were printed, a test chart with 51 random patches for each process color was printed and measured by the inline IQ-501 Intelligent Quality Optimizer. Measurement results were applied to calibrate CMYK curves.
2. G7 gray balance calibration: The P2P51 target was printed and measured by the inline IQ-501 Intelligent Quality Optimizer. Measurement results were applied to correct both CMY and K neutral print density curves (NPDCs), and iterate if needed.
3. ICC profiling: The CGATS IT8.7/4 target with 1,617 patches were printed and measured by the inline IQ-501 Intelligent Quality Optimizer. Measurement results were used to create an ICC profile.

Data Analysis

ICC profiles of the seven substrates were analyzed in the Mac-version CHROMiX ColorThink™ Pro 3.0.9. Their 2D graphs and gamut volumes were compared to find out their differences.

Paper properties of the seven substrates were compared using bar graphs in Excel, and their relationships with color gamut were studied using scatter plots and correlation analysis.

Results and Discussion

The 2D graphs of ICC profiles of the seven substrates are compared in Figure 1. The color gamut boundaries of Mohawk seem to be most outside, followed by Kromekote, while those of Navigator are most inside, indicating a smallest color gamut.

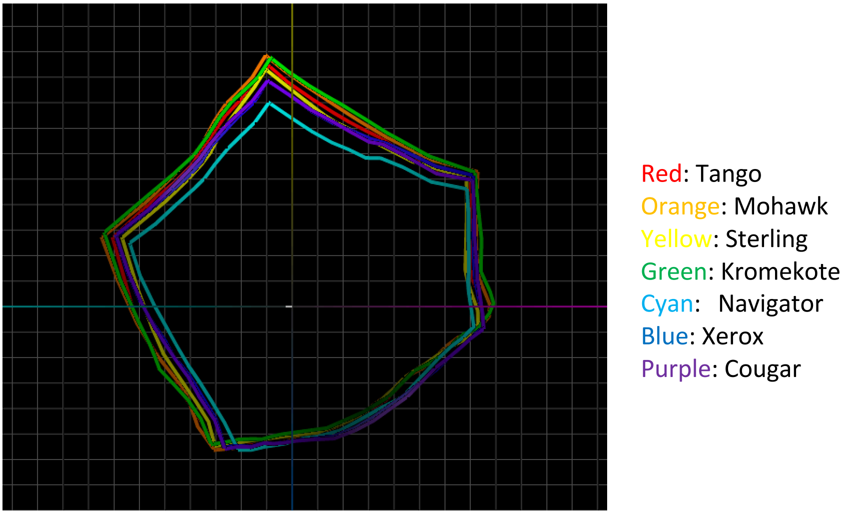

Figure 1: Comparison between the ICC profiles of different substrates

The difference between the ICC profiles can be better illustrated quantitatively by the difference in their gamut volumes, as listed in Table 2. Mohawk achieved the highest gamut volume, followed by Kromekote, while Navigator obtained the lowest gamut volume.

Substrate	***Gamut Volume***
Tango Digital Cover	452,295
Mohawk Everyday Digital	481,476
Sterling Gloss Cover	422,435
Kromekote Gloss Cover	455,706
Navigator Platinum Digital	386,156
Xerox Bold Digital	446,759
Cougar Text	451,552

Table 2: Gamut volume comparison between different substrates

Figure 2 shows the ranking order of the gamut volumes of the seven substrates from the highest to the lowest. The same order was used to compare paper properties first to see if there was a relationship. Correlation analysis was then performed to find out the strength of the relationship.

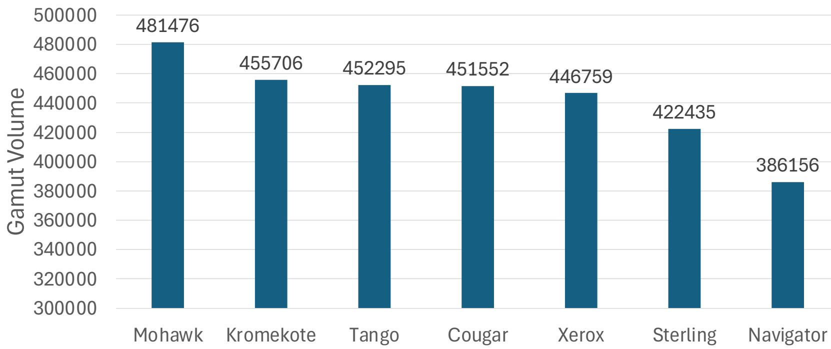

Figure 2: Ranking of the gamut volumes of different substrates

Figure 3 shows the surface roughness comparison. Kromekote (1.19 µm) and Navigator (1.15 µm) have the highest roughness, meaning their surfaces are less smooth, which can impact ink transfer and print uniformity. Cougar and Xerox (1.05 µm each) have moderate roughness, making them relatively smoother than Navigator and Kromekote. Sterling (0.58 µm) has the smoothest surface, followed by Mohawk (0.81 µm) and Tango (0.85 µm), indicating these papers provide a more even print surface, likely enhancing print quality. However, no relationship was found between roughness and gamut volume. Sterling is a coated paper with the lowest roughness, but its gamut volume is the second lowest. Although Kromekote is a high-gloss coated paper with a very shiny surface, its roughness is the highest, but its gamut volume is the second highest. Previous studies have found that paper surfaces that are either excessively rough or overly smooth can lead to issues in the electrophotography printing process. Excessive roughness can result in poor toner transfer, while surfaces that are too smooth may cause feeding problems during substrate transportation within the press [5].

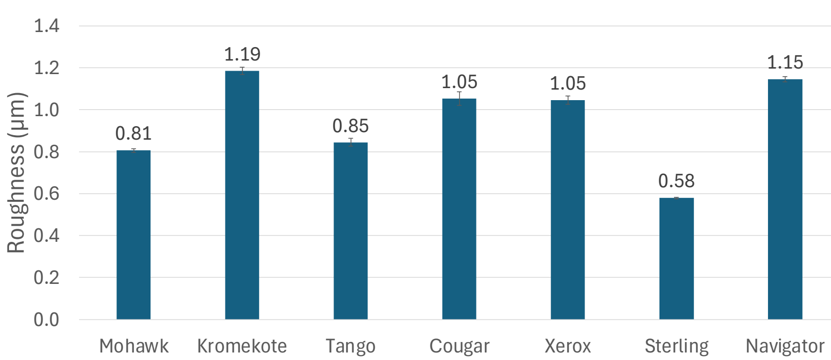

Figure 3: Roughness comparison between different substrates

Permeance and permeability coefficient are compared in Figures 4 and 5, respectively. Navigator (1764 mL/min) has the highest permeance, followed by Xerox (1529 mL/min) and Cougar (1352 mL/min), meaning they allow the highest level of air or ink penetration, which could affect ink drying and absorption. Sterling (1 mL/min), Tango (3 mL/min), and Mohawk (4 mL/min) have extremely low permeance, making them highly resistant to air and ink absorption, which is ideal for applications requiring minimal ink spread. Kromekote (14 mL/min) has slightly higher permeance than that of Sterling, but still much lower than those of uncoated papers like Navigator. Paper permeance and permeability coefficient both describe the movement of air or fluids through a paper substrate, but they differ in scope and measurement. Permeance refers to the rate at which air or liquid passes through the paper under specific conditions, typically measured in mL/min. It depends on both the thickness and the porosity of the paper, meaning a thicker sheet with the same permeability will have lower permeance. Permeability coefficient is an inherent property of the material, independent of thickness, and focuses on how porous the structure itself is. Navigator (0.00968 μm^2) has the highest permeability, followed by Xerox (0.00909 μm^2) and Cougar (0.00888 μm^2), indicating these papers are more porous, allowing ink to penetrate deeper, which then leads ink to lose its density and can negatively affect gamut volume. Sterling (0.00001 μm^2), Tango (0.00003 μm^2), and Mohawk (0.00004 μm^2) have extremely low permeability, making them more resistant to ink penetration and likely better suited for high-quality, detailed printing, and larger color gamut volume. Kromekote (0.00014 μm^2) has slightly higher permeability than that of Sterling, but is still very low.

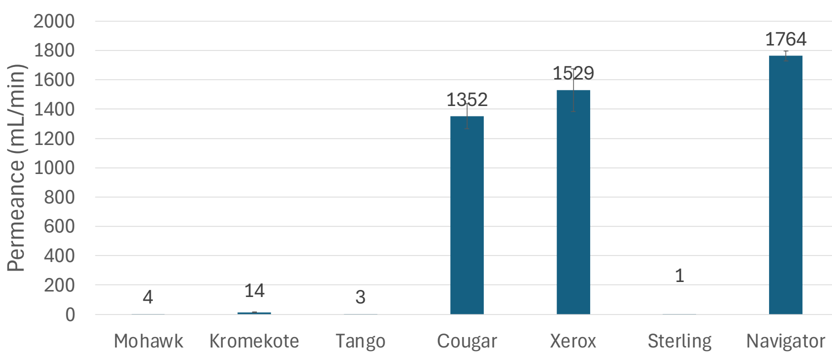

Figure 4: Permeance comparison between different substrates

It was found that papers with lower permeability achieved higher gamut volumes, except for Sterling. Previous studies indicated that toner adhesion and fusing properties were influenced by a paper's porous and permeable structure, which allowed toners to partially penetrate the substrate [6] [7]. Other studies also found that a relationship existed between color gamut and substrate permeability, where substrates with lower permeability exhibited a larger color gamut volume [8] [9].

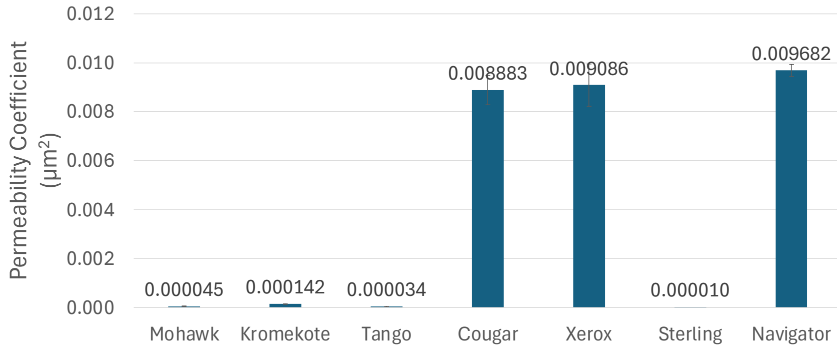

Figure 5: Permeability coefficient comparison between different substrates

Figure 6 shows the gloss comparison. Kromekote (82%) has the highest gloss, making it the most reflective and suitable for applications requiring a shiny finish. Sterling (71%) and Mohawk (62%) also exhibit relatively high gloss. Tango (47%) has a lower gloss, meaning it has a matte finish. The three uncoated papers have very low gloss. No relationship was found between gloss and gamut volume.

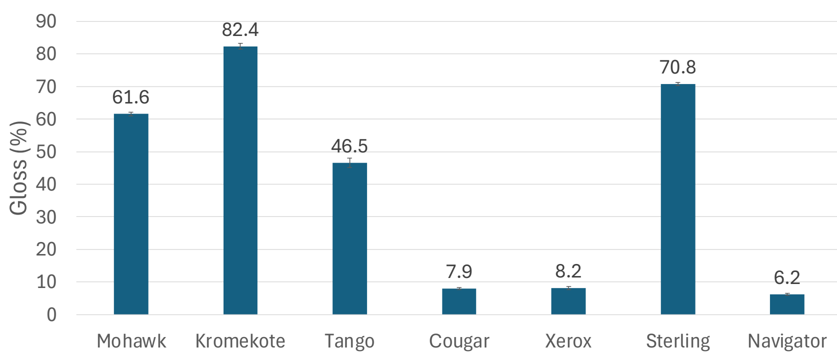

Figure 6: Gloss comparison between different substrates

Figures 7-9 compare CIE L*, a*, and b*, respectively. Xerox (L* = 100.1) is the lightest paper, followed by Cougar (98.8) and Sterling (98.3). The a* values are mostly negative, indicating a slight greenish tint. The b* values vary, with Navigator (-14.7) and Cougar (-10.9) being more blue-toned, while Mohawk (-3.2) and Kromekote (-3.0) are closer to neutral.

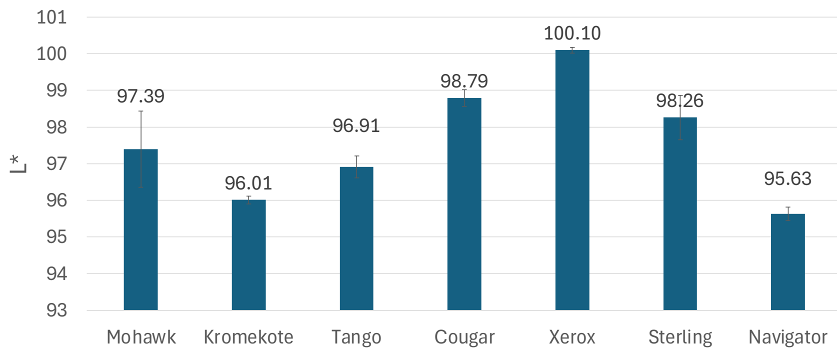

Figure 7: L* comparison between different substrates

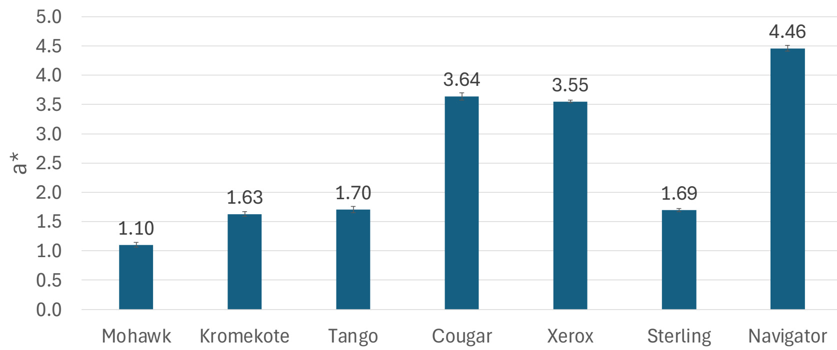

Figure 8: a* comparison between different substrates

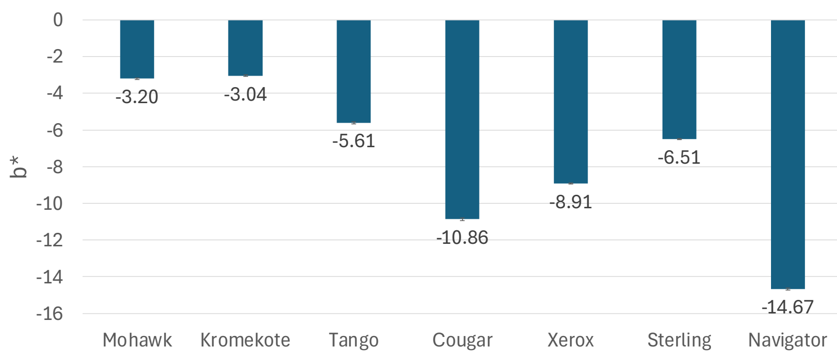

Figure 9: b* comparison between different substrates

Gamut volume is plotted against a* and b* in Figures 10 and 11, respectively. It has been found that the closer to 0 a* and b* are, the higher the gamut volume is. Navigator with the highest a* (4.5) and lowest b* (-14.7) is the furthest from neutral, which resulted in the lowest gamut volume. Paper closer to neutral can reproduce a wider ranges of colors, therefore a larger gamut volume.

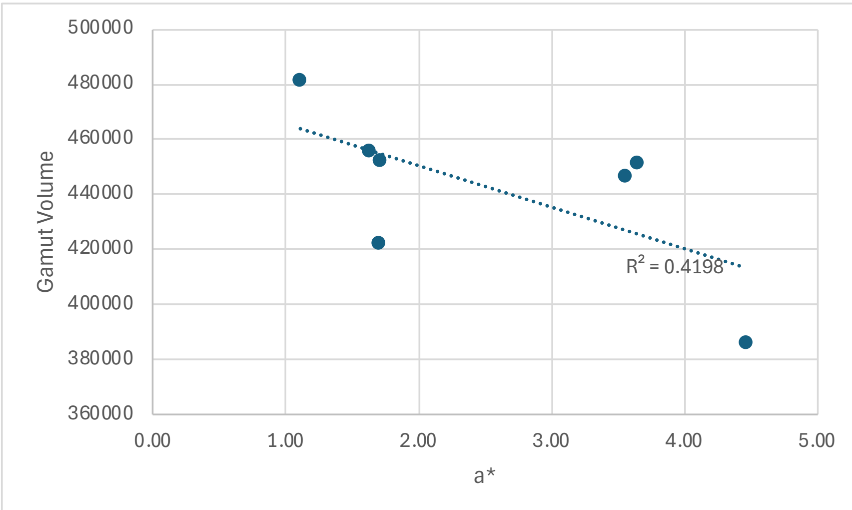

Figure 10: Gamut volume vs. a*

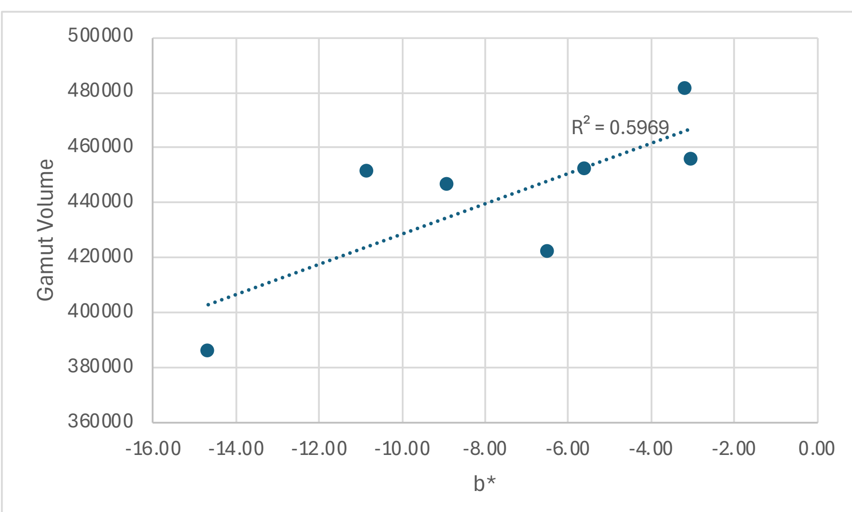

Figure 11: Gamut volume vs. b*

Figures 12 and 13 show the comparisons of whiteness index and yellowness index, respectively. A negative yellowness index indicates a blue cast. Kromekote has the lowest whiteness index and the least negative yellowness index, followed by Mohawk, while Navigator has the highest whiteness index and the most negative yellowness index, followed by Cougar.

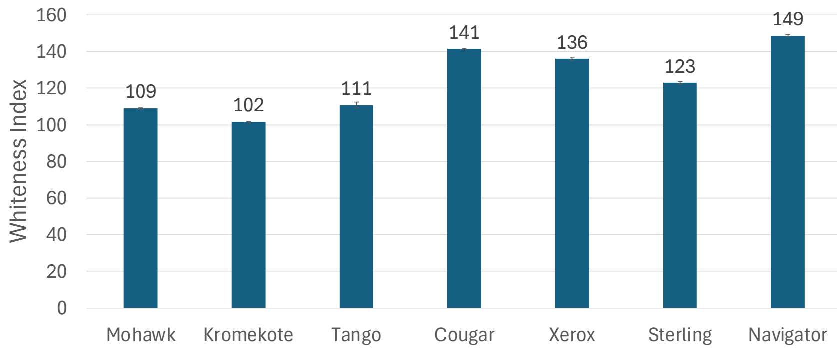

Figure 12: Whiteness index comparison between different substrates

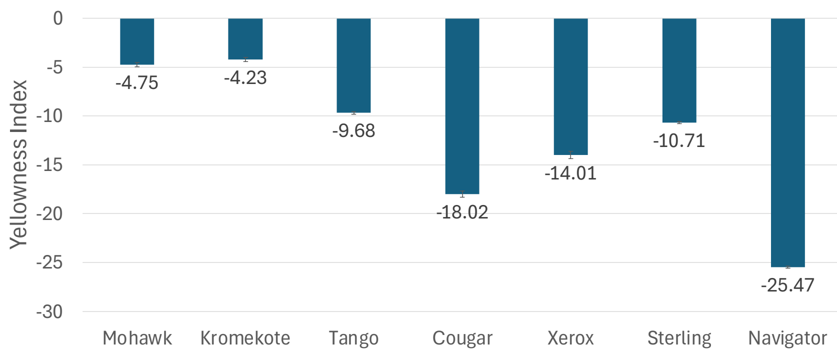

Figure 13: Yellowness index comparison between different substrates

Gamut volume is plotted against whiteness index and yellowness index in Figures 14 and 15, respectively. It has been found that the lower the whiteness index is and the less negative the yellowness index is, the higher the gamut volume is. This confirms previous finding that more neutral paper resulted in a higher gamut volume.

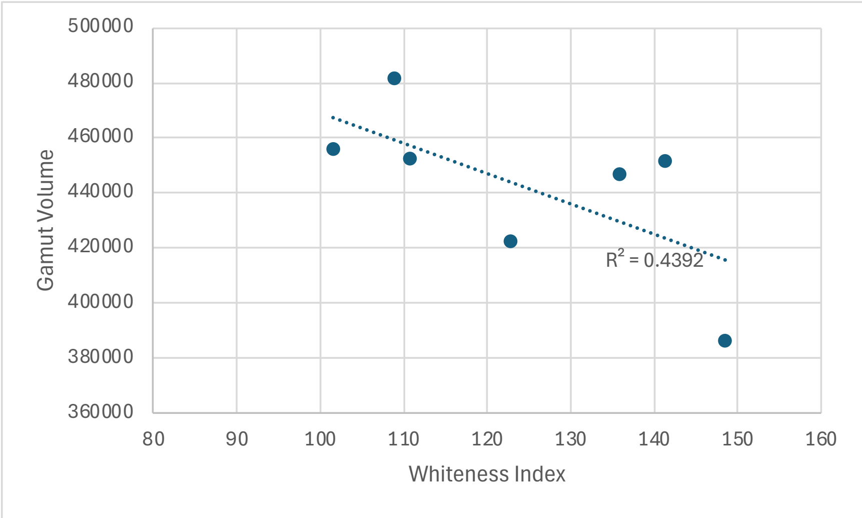

Figure 14: Gamut volume vs. whiteness index

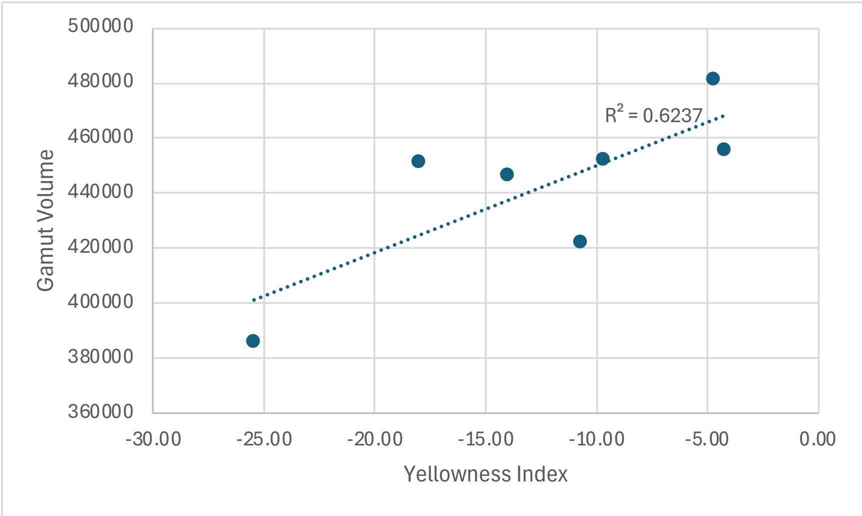

Figure 15: Gamut volume vs. yellowness index

Brightness and OBA are compared in Figures 16 and 17, respectively. Xerox (115%) and Cougar (114%) exhibit the highest brightness, meaning they reflect more light and appear visually brighter. Navigator (110%) follows closely behind, still offering high brightness. Sterling, Tango, Mohawk, and Kromekote have progressively lower brightness, with Kromekote (94%) being the least bright. Papers with high OBA values (Cougar 10.6, Xerox 10.3, and Navigator 9.6) appear brighter under UV light due to fluorescence. Kromekote (4.5) and Mohawk (4.6) have the least OBA, making them less bright under UV conditions. With lower brightness and lower OBA, Kromekote and Mohawk achieved higher gamut volume.

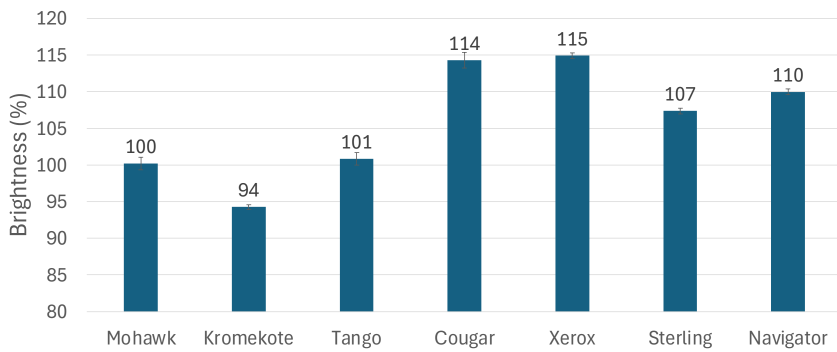

Figure 15: Brightness comparison between different substrates

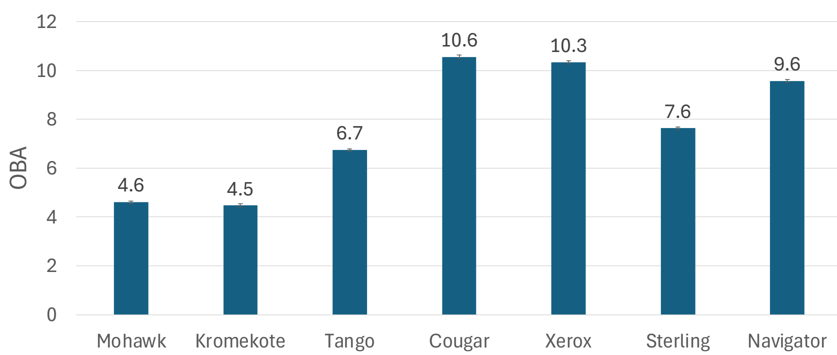

Figure 16: OBA content comparison between different substrates

Conclusions

In this study, a Konica Minolta AccurioPress C2070 was used to study how paper properties affect color gamut of dry-toner EP. Seven paper substrates, three uncoated and four coated, were selected, and their structural and optical properties were measured. Their ICC profiles were created and gamut volumes were compared. It was found that paper optical properties affected the color gamut of EP more than structural properties. Achieving a higher gamut volume of EP requires lower yellowness index and whiteness index, a* and b* (or chroma) closer to 0, less OBA content, and lower permeability.

Acknowledgement

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