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Possibility of Realisation White Electroink on a Metallised Printing Substrate

ABSTRACT

White printing is a general trend necessary for the production of printed media on highly saturated substrates and transparent surfaces. Such industrial printing is achieved primarily via classical technologies. However, electrophotography with liquid white ElectroInk is now increasingly common. A new trend is printing ElectroInk white on metallised substrates, where it serves as a base layer (mask) for subsequent in-line CMYK colour reproduction. Applying white ElectroInk in thicker layers is challenging. Achieving higher TiO2 pigment concentration requires more white layers. In this work, the reproduction of standard white ElectroInk is investigated on an HP Indigo WS 6800 machine, using one, two, and three machine prints repetitions. To enhance the white ink effect, experimental embossing of the metallised substrate (Vacuum metal silver lux ultra ws label material) will be performed with the Pantek Rhino S510 unit. This process forms a rough surface layer using two embossing plates. Printing white ElectroInk and overprinting on such a surface introduces a new challenge. It creates visual effects with better white acceptance on the metallised surface. Experiments show the best sample is the one printed on an HP Indigo machine with two coats of white ElectroInk. It was also found that changing the surface structure with embossing causes greater changes at higher white tone coverage. White halftone patches achieve rapid tone change (1 layer: ΔE_{00}=1.95; 2 layers: ΔE_{00}=2.34; 3 layers: ΔE_{00}=1.55), while solid tones change slightly (1 layer: ΔE_{00}=1.55; 2 layers: ΔE_{00}=0.70; 3 layers ΔE_{00}=0.32).

Igor Majnarić
Ivana Bolanča Mirković
Meri Huljev
Stanko Bauk

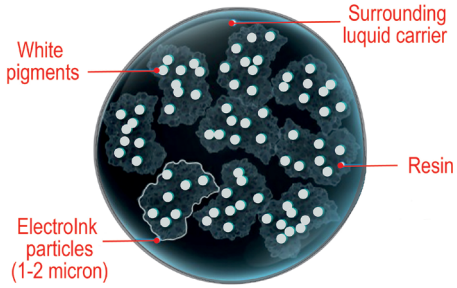
University of Zagreb,
Faculty of Graphic Arts,
Zagreb, Croatia

KEY WORDS
Digital colour offset, embossing, white electroInk, metallised substrate

1. Introduction

Special printing effects are often achieved through the use of white ink. In modern printing houses, electrophotographic (EP) and inkjet machines are increasingly equipped to apply specialized white inks and toners (Majnarić, 2015). The ability to produce high-quality personalized prints and manage small, frequently repeated print runs is one of the main advantages associated with white ink (Kipphan, 2001). Depending on the type of printed product, spot white ink can be applied to substrates with intense colors or used as masks on completely transparent substrates. This allows for the subsequent printing of process inks, which prevents the transparency of the substrate and enhances the contrast of the final color print (Gorski, 2026). Electrophotographic HP Indigo machines are utilized with a specialized liquid printing ink known as ElectroInk. This ink is designed for Digital Colour Offset technology and is characterized by its low viscosity. During the printing process, a solid state is achieved by the ink through polymerization and the temperature-driven evaporation of the volatile Isopar solvent, resulting in a pasty adhesive substance (Landa et al., 1988). ElectroInk is

categorized as an EP ink and is composed of several key components. Pigments in the form of a thermal polymer (24-29%) are dispersed in a non-polar volatile oil (70-75%). Additionally, additives to enhance conductivity (approximately 10%) and charged pigmented toner particles suspended in a liquid carrier are included in the formulation. To attain maximum opacity in the printed image, the proportion of white ElectroInk pigment particles (paste) is required to be optimized (Forgacs & Teishev, 2013; Morić, Majnarić & Modrić, 2020).



» **Figure 1:** *Schematic representation of white ElectroInk for HP Indigo machines*

2. Theoretical part

white printing inks are expertly crafted using white pigments and fillers that reflect nearly 100% of visible light, resulting in a brilliantly bright white appearance. the most notable chemical compounds that contribute to this exceptional whiteness include titanium dioxide (tio2), zinc oxide (zno), calcium carbonate (caco3), aluminum oxide (al2o3), silicon dioxide (sio2), magnesium oxide (mgo), and barium sulfate (baso4). in the market of printing inks, ten key white pigments and fillers stand out, each selected for their optimal concentration and particle size. these include zinc white, lithopone white, zinc sulfide, bleached calcium carbonate, china clay, blanc fixe, aluminum hydrate, talc, and silica.

2.1. Zinc white - chinese white

Zinc white pigments are bright white with medium opacity, providing reliable coverage for industrial applications. Finely ground, they meet FDA approval, exhibit strong UV absorption, and resist fungal growth. Their alkaline nature neutralizes oxidation products and makes them suitable for acidic resins. Color changes occur with copper compounds, showing yellow in warm conditions and white in cold. Used as fillers in can printing and other inks, these pigments enhance flow and application. Cl White 4 (Cl No. 77947; CAS No. 1314-13-2) consists of 99% to 99.7% zinc oxide (ZnO) and 0.3% to 1.0% volatile solvents (Leach & Pierce, 1999).

2.2. Lithopone white

Lithopone white pigment is chemically inert, making it compatible with formulations that include TiO2. Available in micro-sized particles, it acts as a white, transparent filler that is acid-degradable. It is made from calcined copper pyrite, zinc sulfide, and barium sulfate, and is increasingly used as a filler in TiO2 systems. Cl Pigment White 5 (Cl No. 77115; CAS No. 1345-05-7) consists of approximately 60% to 72% barium sulfate (BaSO4) and 28% to 40% zinc sulfide (ZnS) (Leach & Pierce, 1999).

2.3. Titanium dioxide - anatase and rutile structure

Titanium dioxide is the most widely used white pigment due to its high refractive index and excellent opacity. It has largely replaced other pigments due to its resistance to various pH levels and stability under light and heat. Unlike zinc, aluminium, zirconium, or silicon oxides, titanium dioxide can be coated in multiple ways. Understanding its safety profile and environmental impact is crucial for industry professionals, as these factors influence regulatory compliance and sustainability. There are two primary crystal forms: rutile, which is harder and more durable with a higher refractive index (2.71), and anatase, which is softer and has a lower refractive index (2.55) and lower hiding power. Rutile is suitable for long-lasting coatings, while anatase is preferred for applications requiring a bluer tone and increased translucency.

Titanium dioxide pigment is widely used in various ink systems. Pure, uncoated pigment is often used in water-based flexographic and screen printing inks, while surface-treated pigments enhance print quality and gloss but are less transparent. These coated pigments require specific dispersion techniques and are primarily used in lithographic offset and letterset printing, where high-whiteness substrates are preferred for tone tinting (Tomerlin et al., 2023).

Ilmenite ($FeTiO_3$) is processed to produce titanium dioxide (TiO_2) pigments by treatment with sulphuric acid, followed by hydrolysis, calcination at around 1000 °C, wet-milling, and finishing steps such as washing and drying. Alternatively, in the chloride process, titanium-rich feedstock is chlorinated to form titanium tetrachloride ($TiCl_4$), which is subsequently oxidised to form TiO_2. Both processes are used for the production of pigment-grade TiO_2. Newer methods produce easier-to-disperse particles with high opacity and gloss, with crystal sizes around 0.2 µm, which helps optimise visible-light scattering. C.I. Pigment White 6 (C.I. No. 77891; CAS No. 13463-67-7) typically consists of 80% to 99.9% TiO_2, with up to 20% additional oxides and a small organic coating (Leach & Pierce, 1999).

2.4. Zinc sulphide

Zinc sulphide is an opaque white pigment known for excellent abrasion resistance and higher UV reflectance than titanium dioxide (TiO_2). It resists most liquids except acids and offers good heat and ageing resistance. While not as opaque as TiO_2, it effectively serves as a filler for TiO_2 in various formulations. This pigment can be used in all printing techniques, except with acidic resins or in metal decoration applications, which require a clear enamel after baking. C.I. Pigment White 7 (C.I. No. 77975; CAS No. 1314-98-3) has the following composition: ZnS (97%), ZnO (less than 0.3%), solubles (less than 0.4%), moisture (less than 0.2%), and residue (3%) (Leach & Pierce, 1999).

2.5. Bleached calcium carbonate

Bleached calcium carbonate ($CaCO_3$) is a cost-effective white filler used in printing inks, enhancing quality while reducing costs. It often contains up to 3% stearate or resin, and both coated and uncoated forms are available with larger particle sizes, which contribute to good workability and a glossy finish. The opacity of the pigment varies from opaque to translucent, depending on grinding intensity. This pigment is used in various inks, including letterpress, offset lithography, and gravure, achieving a matte finish. When added to copper plate pigments, it improves adhesion to substrates. However, it should not be mixed with acidic binders due to reactivity with moisture and potential reactions with certain pigments.

Calcium carbonate also serves as a dusting powder to prevent smudging. Higher-quality ground mineral versions, particularly from Japan, offer high gloss and transparency but come at a higher cost. Calcium carbonate ($CaCO_3$) occurs naturally in forms such as chalk and limestone. It can be obtained by grinding natural mineral sources or synthesised by slaking quicklime and subsequently reacting it with carbon dioxide. It is also a by-product of water purification. The composition of Natural C.I. Pigment White 18 (C.I. No. 77220; CAS No. 471-34-1) varies based on its source: it typically contains 95% to 98% $CaCO_3$, 1% to 3% $MgCO_3$, and trace amounts of other compounds. The synthetic version is purer, with 98% to 99% $CaCO_3$ and lower levels of impurities (Leach & Pierce, 1999).

2.6. China clay (kaolin)

China clay is a white to pale grey, chemically inert powder with a high absorption capacity for printing oils. It is commonly used to produce inexpensive, moisture-resistant white inks and also acts as a thickening agent. China clay is also approved by the FDA for certain applications.

China clay is primarily composed of naturally occurring hydrated aluminium silicate and often contains impurities such as calcium, magnesium, iron, quartz, and mica. Purification is achieved through levigation and settling tanks. The composition of C.I. Pigment White 19 (C.I. No. 77005; CAS No. 8047-76-5) varies by medium and calcium content. For instance, the aqueous version typically contains 37–45% Al_2O_3 and 44–53% SiO_2, while the calcined version contains 42–45% Al_2O_3 and 51–53% SiO_2, with minimal impurities (Leach & Pierce, 1999).

2.7. Blanc fixe, process white

Blanc fixe is a high-quality white filler known for its resistance to all pH levels, good light fastness, and thermal stability. It has high diffuse light reflectance, maintaining gloss and tone when mixed with other colors. Primarily used in inks for pastel colors, its high density allows for significant weight additions without affecting print yield. Its safety is confirmed by FDA approval and low solubility. Cl Pigment White 21 (CI No. 77120; CAS No. 7727-43-7) has the following composition: BaSO4 (97% to 99%), SiO2 (0% to 2%) Residues (0% to 1%) (Leach & Pierce, 1999).

2.8. Aluminum hydrate, lake white, transparent white

Aluminium hydrate ($Al_2O_3 \cdot H_2O$) is a versatile white filler known for its soft texture and transparency. It is resistant to most chemicals, except for dilute hydrochloric acid (HCl), ensuring reliable performance in various applications. This filler offers thermal stability and lightfastness and improves the flowability of lithographic offset inks and varnishes. Available in formulations with different viscosities, ranging from pastes to liquids, it is a cost-effective and easily dispersible option that is FDA-approved. C.I. Pigment White 24 (C.I. No. 77002; CAS No. 1332-73-6) (Leach & Pierce, 1999).

2.9. Talc, french chalk

Pure talc has a hardness of 1 on the Mohs scale, while diamond has a hardness of 10 (International Gem Society , 2025). It appears as a shiny, very fine white powder that is chemically inert, light-resistant, and can withstand temperatures up to 850 °C. Talc is commonly used as an inexpensive filler in high-quality lithographic offset inks, where it helps reduce tack and improve rub resistance. Composed mainly of magnesium silicate, talc occurs naturally in mineral deposits and is commonly associated with soapstone. For C.I. Pigment White 26 (C.I. No. 77718; CAS No. 8005-37-6), the typical composition includes 25% to 30% magnesium oxide, 52% to 56% silicon dioxide, and smaller amounts of calcium oxide, iron(III) oxide, and aluminium oxide. In the pure pigment variant, the magnesium oxide content increases to 31% to 32%, and the silicon dioxide content to 60% to 64%, with reduced levels of other components (Leach & Pierce, 1999).

2.10. Silica

Silica is a lightweight, transparent white filler with a matting effect, high oil absorption, and chemical inertness, making it stable in various applications. It is used as a filler in inks, preventing the settling of other particles and reducing tack and gloss. It can also form gels when dispersed in non-polar solvents. C.I. Pigment White 27 (C.I. No. 77811; CAS No. 7631-86-9) consists of 98% SiO_2 and 0.1% other oxides, with a loss on ignition of 2.0% (Leach & Pierce, 1999).

3. Experimental part

For this study, an SRA3+ test motif featuring multiple white halftone wedges ranging from 0% to 100% tone value (TV), in 10% increments, was created. The test motif was designed in Adobe Illustrator 2022, saved in PDF/X-4 format, and loaded into the RIP (ESCO, HPE ProLiant ML350) using the standard LUT 0.5 calibration curve (Majnarić et al., 2025). White ElectroInk was used for printing on the HP Indigo WS6800, with a varying number of ink layers. The printing substrate used in this experiment was the metallised foil Vacuum Metal Silver Lux Ultra WS/SH6020 Plus/WG80, which was printed using two different methods (Fedrigoni Group, 2026).

In the first part of the experiment, direct white printing was performed on the metallised foil layer using the HP Indigo WS6800. In the second part, the metallised foil was embossed using the Pantec Rhino S 510, resulting in a relief structure on the foil (Rhino, 2026). Following embossing, white ink was printed on the structured metallised aluminium self-adhesive foil using the HP Indigo WS6800 (HP Indigo, 2026). A total of two sets comprising six samples were created using the HP Indigo WS6800 printer. The first set was printed with one, two, and three layers of white ElectroInk. The second set was printed with one, two, and three layers of white ElectroInk on embossed metallised foil. All samples with white imprints were adhered to a 4 mm-thick glass surface after removal of the liner. This setup was designed to simulate realistic measurement conditions corresponding to the application of the printed foil to a glass bottle. A 1 kg FINAT roller with a hardness of 70° Shore was used to apply the printed foil (FINAT, 2019).

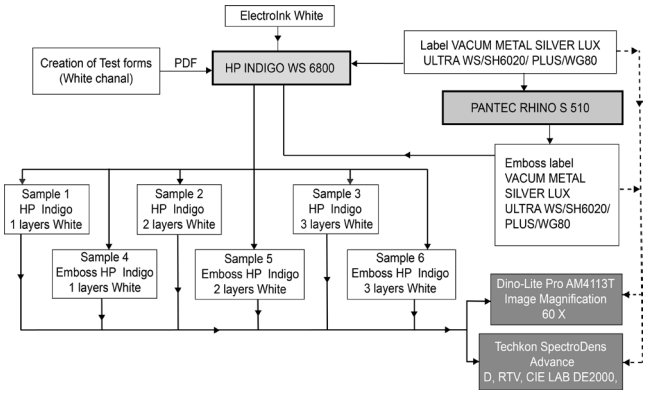
All generated white samples (S1, S2, S3, S4, S5, and S6) were subjected to optical measurements using a Techkon SpectroDens spectrophotometer/densitometer. CIE Lab* values, optical density (D) of the various white ink coatings, colour differences (CIEDE2000, ΔE_{00}), and tone values (TV) were obtained from the measurements (Techkon, 2026). The final results were processed and presented using OriginPro 8.5, while enlarged images were examined using a Dino-Lite AM4113T microscope. Additionally, all images were processed in Adobe Photoshop 2022. The chronological flow of the experiment is illustrated in Figure 2.

4. Results and discussion

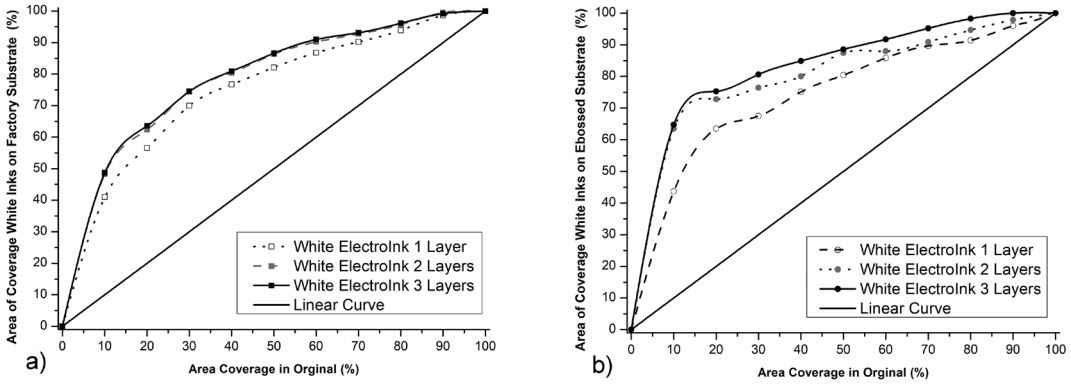
4.1. Densitometry

A modified densitometric method was utilised to evaluate white ElectroInk deposits. With increasing whiteness, the densitometric values of the reproduction curve decrease; therefore, the corresponding deviations are represented in the negative coordinate space. In the analysis of print reproduction, reproduction curves are commonly generated by plotting the tone value specified in the digital file against the measured tone value of the printed reproduction, covering the range from 10% to 100% TV in increments of 10%. Figure 3 shows the reproduction curves for the HP Indigo WS6800.

The largest deviations in white tone reproduction occur within the medium-to-high halftone range, particularly between 40% and 60% TV, while notable differences are also observed between 10% and 20% TV. As the number of white ElectroInk layers increases,



» **Figure 2:** *Schematic representation and chronology of the performed experiment with the application of measuring equipment and materials*



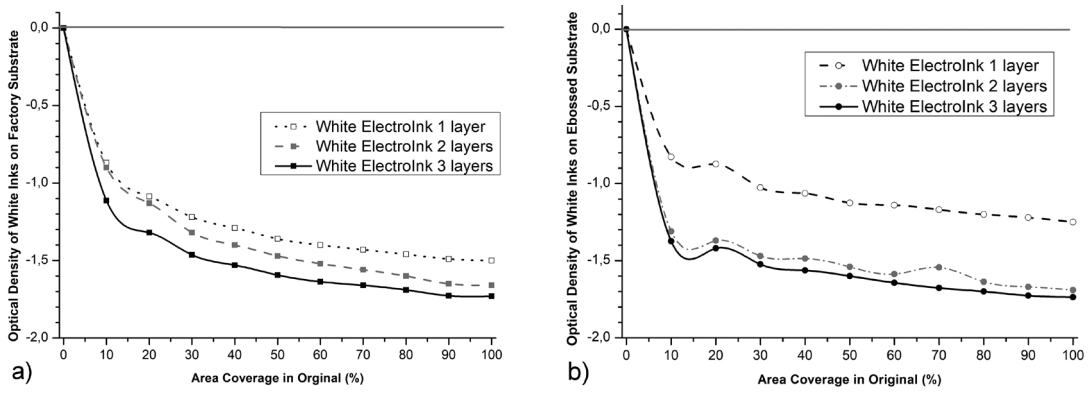
» **Figure 3:** *ElectroInk white reproduction curves printed on the HP Indigo WS6800: a) original (factory) metallised substrate; b) embossed metallised substrate*

TV gain also increases. There are no substantial differences between two and three layers of white, with consistent average gain values, such as ΔTV_W1layer_W2layer = 7.9% at 10% TV. For prints with two and three layers of white, the average gain remains at 4.28%, with ΔTV_(2layer_3layer) also at 7.9%.

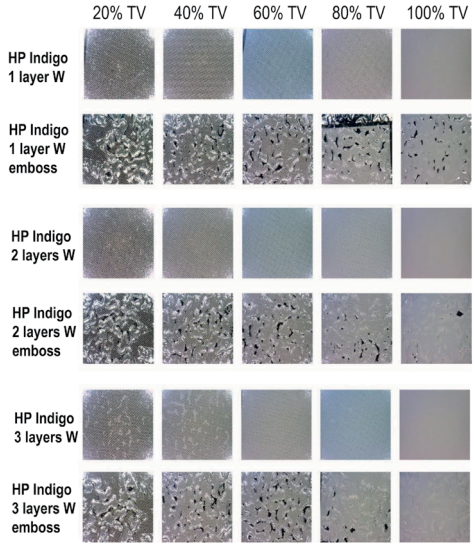
Patterns on embossed metallised substrates exhibit visible differences depending on the number of white ElectroInk layers, with smoother tonal gradations on roughened surfaces compared with smooth surfaces. Light-tone reproduction shows pronounced deviations, with ΔTV_W10% = 20.93% for both one and two layers of white. For medium halftone values, the difference between the first and second layers is ΔTV_W1layer_W2layer = 7.46%, while the addition of a third layer results in a further difference of 3.44%. In darker TV areas, minor tone-value differences occur between layers, with ΔTV_W60%–W90% = 2.23% for one versus two layers and 3.51% for two versus three layers. Accurate reproduction of white tones depends on the optical density of the solid white ink layer, which also affects the optical densities of the halftone areas. Figure 4 shows the relationship between the optical density of the white fields and tone value.

When using the HP Indigo, a double layer of white ink produces an average optical density (D_avg) of 0.15. Adding a third layer results in an additional optical density increase of ΔD_avg = 0.07. The difference in optical density between one and two layers increases, with an average difference from 20% TV to 90% TV of ΔD_W20%–W90% = 0.12. For the third layer, this value is ΔD_W20%–W90% = 0.11.

Figure 4b shows the tone-range curve for white ElectroInk on an embossed metallised substrate. With one and two layers, a deviation of ΔD_W100% = 0.44 occurs at the solid area (100% TV), while adding a third layer results in a minor deviation of ΔD_W100% = 0.05. The average optical density difference between 10% TV and 90% TV is ΔD_W1layer_W2layer = 0.45. The addition of a third layer does not substantially change the optical density, with ΔD_W2layer_W3layer = 0.07. Ultimately, a third layer of white ElectroInk is mainly beneficial for achieving solid areas, as illustrated in Figure 5 by enlarged microscopic images (60×) obtained using a Dino-Lite microscope.



» **Figure 4:** *Densitometric curves of ElectroInk white ink printed with the HP Indigo WS6800: a) original (factory) metallised substrate; b) embossed metallised substrate*



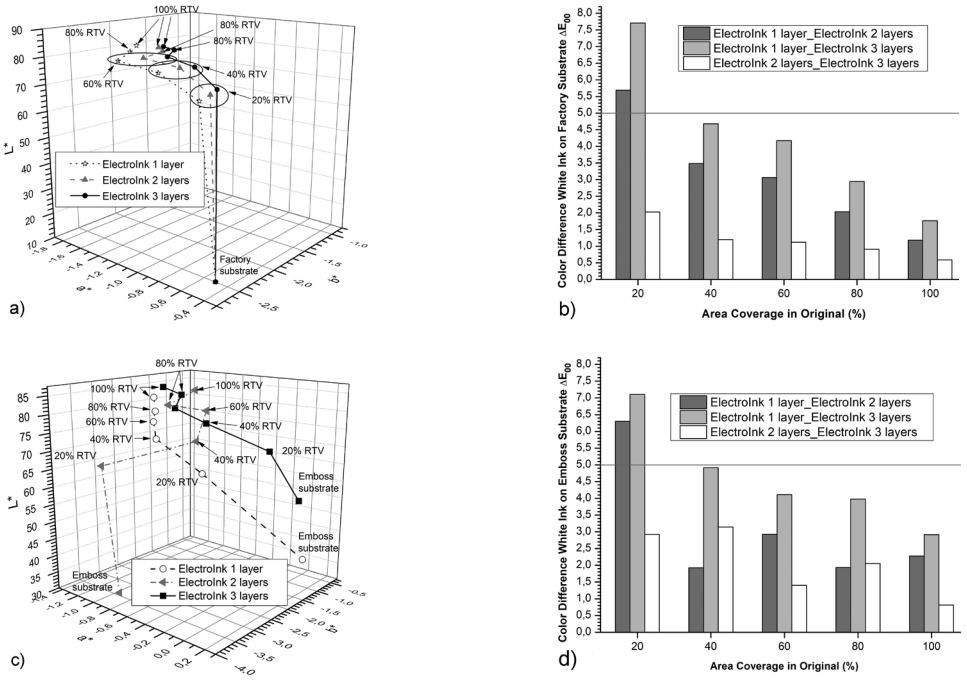
» **Figure 5:** *Microscopic images of imprints on five characteristic patches on embossed and original metallised surfaces printed using the HP Indigo WS6800*

4.2. Colourimetric analysis of white prints

The modified densitometric method used in this study is less suitable for assessing white surfaces, as the measurement is influenced by the optical properties of the white colourant and the aluminium metallisation of the self-adhesive foil. This makes comparisons across different experimental settings challenging, especially for materials with different surface structures. In contrast, colourimetry provides a more appropriate basis for evaluating and comparing colour differences in relation to human visual perception. Figure 6 illustrates the colour variations resulting from printing with different numbers of white ElectroInk layers.

Figure 6a illustrates a three-dimensional representation of different applications of white ink on an original metallised surface printed using the HP Indigo. Applying white ink markedly increases lightness (L*) at 20% tone value (TV). As surface coverage increases, more noticeable changes in chromaticity occur, while changes in lightness become smaller. Increasing TV shifts chromaticity along the negative b* axis of the CIE Lab* colour space, giving the white a more bluish hue. Up to 60% TV, all layers of white ElectroInk display similar changes. Beyond this point, there is a noticeable shift along the positive a* axis, resulting in a warmer shade of white.

Figure 6b displays the colour differences between different layers of white ink printed using the HP Indigo. The bar graph shows that as the tone value increases, the colour difference between white ElectroInk imprints decreases. Notably, prints with two layers exhibit greater colour differences than those with three layers. The largest colour difference occurs at 20% TV, where the differences exceed the defined quality threshold of $\Delta E_{00} = 5$. The recorded colour difference between one and two layers is ΔE_W1layer_W2layer = 5.7, and that between two and three layers is ΔE_W2layer_W3layer = 7.7, the largest value recorded in the study. As the coverage of white ElectroInk increases, the colour differences decrease,



» **Figure 6:** *Colourimetric changes of white ElectroInk on the HP Indigo WS6800: a) 3D CIE Lab representation of prints on an original metallised surface; b) ΔE_{00} colour differences on an original substrate; c) 3D CIE Lab* representation of prints on an embossed metallised surface; d) ΔE_{00} colour differences on an embossed substrate*

reaching the lowest values at the solid tone (100% TV), with ΔE_W1layer_W2layer = 1.2, ΔE_W1layer_W3layer = 1.8, and ΔE_W2layer_W3layer = 0.6. Differences of $\Delta E_{00} < 1$ are typically imperceptible to the human eye.

After embossing, the roughness of the metallised surface markedly affects the applied white ink layer. The three-dimensional graph in Figure 6c shows the variations in these layers on an embossed metallised substrate printed using the HP Indigo. When one layer of white ElectroInk is applied at 40% TV, noticeable changes in lightness and chromaticity occur, with additional layers primarily affecting lightness.

The largest chromaticity changes occur along the positive b* axis, leading to yellowing. With two layers of white ink, changes in lightness are stable up to 20% TV, while only minor changes are subsequently observed along the positive a* axis. For white tones above 60% TV, fluctuations in lightness and chromaticity are minimal. Three layers show pronounced changes in lightness from 20% to 60% TV, accompanied by chromaticity changes along the a* axis, while darker tones shift towards a bluer appearance.

Figure 6d shows the colour differences (ΔE_{00}) among prints with one, two, and three layers of white ElectroInk on an embossed metallised substrate printed using the HP Indigo. The embossed samples exhibit more pronounced variations in white tones than samples printed on the original smooth substrate. The largest colour difference, ΔE_W1layer_W3layer = 7.20, is observed at 20% toner coverage between one and three layers of white. As white coverage increases, the average colour difference between one and two layers is ΔE_W1layer_W2layer = 2.20 for 40% to 100% TV. When comparing one and three layers, the mean difference increases to ΔE_W1layer_W3layer = 3.90. The smallest mean difference, ΔE_W2layer_W3layer = 1.90, is found between the second and third layers, with a minimum difference of ΔE_W2layer_W3layer = 0.80 at 100% TV.

5. Conclusions

Densitometric measurements on a metallised substrate showed that the smallest average tone-value gain was obtained with a single layer of white ink printed using the HP Indigo, with ΔTV = 77.32. No substantial differences in tone-value gain were observed in the white midtones when comparing two and three layers of white ink, both showing a tone-value gain of approximately 4% compared with one layer.

For embossed prints with one layer of white ink, the quality of intermediate white tones was comparable to that obtained on smooth surfaces. Additional layers of white ink led to increased tone-value gain, reaching 2.38% for two layers and 5.74% for three layers. Variations in optical density were also observed, with Dmax changing from –1.29 for one layer of white to –1.73 for three layers. On an embossed substrate, the tone value decreased only with one layer; however, two and three layers maintained the tone value in the solid area, indicating effective ink filling.

Colourimetric measurements revealed that the largest fluctuations in white tones occurred with three layers of white ink on the original substrate printed using the HP Indigo, resulting in an average colour difference of ΔE_avg = 4.88 and a colour difference of ΔE_W100% = 1.76 at 100% TV. On the embossed substrate, similar variations were observed, with ΔE_W100% = 2.91.

For a solid white field, the colour difference with one layer of ElectroInk was ΔE_W100%_1layer = 1.54, decreasing to ΔE_W100%_2layer = 0.70 with two layers and further to ΔE_W100%_3layer = 0.35 with three layers. In halftone patches, the colour differences were ΔE_{00} = 1.95 for one layer, ΔE_{00} = 2.34 for two layers, and ΔE_{00} = 1.55 for three layers. Overall, increasing the number of white ElectroInk layers improved solid-white reproduction, while the effect of additional layers was more pronounced on embossed metallised substrates.

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