CLEMSON TAGA

TAGA Annual Technical Conference 2020

Dear Reader and Fellow Graphic Arts Enthusiasts,

Thank you for taking the time to review our research. We know that there is a great deal of terrific material at the conference this year, as always. We are grateful that you are taking time to evaluate ours.

Clemson has been participating in the TAGA conference for over 30 years. (Go Tigers!). We were mentored by Dr. Liam O'Hara once again and we are immensely indebted to him for all his advising and teaching.

In Clemson's Graphic Communications program, students are united through their knowledge of print production and graphics. Through lectures and hands-on labs, we are able to immerse ourselves in both technical principles and physical print production. As valuable as our shared experiences are, equally important are the factors of our program that allow us to set ourselves apart from one another and explore our interests. Research is one of these diversifying factors that allows students to independently explore a topic of interest.

I'm incredibly proud of this year's TAGA team for all of their time and effort spent on planning, designing, and producing this journal. To be a part of such a hard-working and dedicated group has been an honor. Watching my peers take advantage of every opportunity the program has to offer has been truly exciting.

Lastly, we are proud to be part of the TAGA Conference again this year and to be supporting the advancement of knowledge in the Graphic Communications discipline as the industry continues to advance. We hope to learn as much from the other research submitted this year as we hope you will learn from ours.

Teresa Clancy

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Clemson University TAGA Chapter
President 2019-2020

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CH. 1 A METHOD TO ALTER POLYMER SWELLING PERMANENT TOPOLOGICAL EFFECTS

Cat Bromels[1], Anna Railanmaa[2], Don Lupo[2], and Charles Tonkin[1]

Introduction

Real-time health monitoring, Internet of Things devices (IoT), and sensors are in ever-increasing demand. Development of smaller, ultraflexible wearable devices are at the forefront of research to meet these demands (21). Printed and organic electronics offers proven and patented, low-cost, high processing volume products that are recyclable or incinerable with standard household waste (9, 12, 16, 17, 21). For these types of small temporary devices, cost and end of life disposal must be considered; for wearables, additional concerns of flexibility, minimal profile, unobtrusive devices that contain only non-toxic and non-corrosive materials must be considered during research if results are to be useful for production-level applications.

Though rigid batteries (printed or otherwise) can meet the energy requirements of wearable health-monitoring systems, they are typically too bulky to be worn comfortably, and printed flexible batteries available currently are cost prohibitive. Additionally, batteries generally contain noble or heavy metals—such as lithium, silver, or manganese—which are corrosive and difficult to dispose of (5, 9, 10). Autonomous printed energy harvesting systems (e.g. ambient light, radio-frequency fields, vibrations, etc.) can provide enough energy and printed supercapacitors can provide the backup storage needed to fuel systems when the primary energy source is not available (2,

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5, 7, 12, 21). Additionally, both of these solutions can be printed with completely non-toxic, non-corrosive materials that are environmentally friendly, and that pose no adverse reactions to the end-user in the event of a mechanical breakage (5, 9, 10, 12, 16, 21). It should be noted that the only portion of a supercapacitor which has the potential to leak out of the device is the electrolyte, but studies have proven that non-corrosive and non-toxic aqueous alternatives, (e.g. table salt and water) are viable (10, 18).

Supercapacitors—also known as ultracapacitors or electric double-layer capacitors (EDLC)—are rechargeable electrochemical energy storage devices that can store and release energy almost instantaneously. Their basic construction is two porous electrodes connected to current collectors with a separator and electrolyte between them, all of which can be fabricated using non-toxic biodegradable or incinerable materials (5, 7, 9, 10, 11, 13, 16, 18, 20). Additionally, supercapacitors have a low production cost, are well studied, and are already in use for a variety of applications from standalone low-power electronics to grid-level electrical storage (5, 11).

Background

This study builds upon the printed supercapacitor research at the Laboratory for Future Electronics at Tampere University (formerly Tampere University of Technology). Flexible super-capacitors have been previously fabricated on paper or PET substrates (7, 8, 10, 12, 13, 16, 18) which are not ideally suited for skin-conformable, wearable applications.

Thermoplastic Polyurethane (TPU) was chosen as an ideal substrate for development of skin-mountable devices. Covestro Platilon® 4201 AU 50μm was chosen for its high elasticity, use in current medical applications, documented printability, and breathable but watertight properties. The current collector ink—Henkel Electrodag® PF407C graphite ink—from previous studies (10, 13, 16) was chosen for its low resistivity (10 Ohm/square [Ω/□] as specified by manufacturer), incinerable properties, and its ability to be prepared in any environment.

A key performance parameter of a supercapacitor is the Equivalent Series Resistance (ESR), which limits the maximum discharge current. Although extremely rapid discharge is not a major issue for printed supercapacitors for use in distributed smart devices—in contrast to applications such as grids or electric vehicles—the ESR still needs to be low enough to power measurements and possible radio transmissions. For supercapacitors using metal-free current collectors, it was found that the largest contributor to ESR is the sheet resistance of the current collector (13). Additional factors contributing to the ESR include the resistivity of the electrode (including the resistivity of the electrolyte within its porous layer) and the contact resistance between the electrode and the current collector (14, 22). The current collector is responsible for charge transport during the charge-discharge process, and research has indicated that increasing interfacial contact between the current collector and the electroactive materials will increase efficiency, increase rate capability, decrease impedance, lower the charge transfer rate, and improve storage capability (14, 22).

Fabrication and Measurement Baseline

The capacitance of a printed supercapacitor is directly linked to the thickness and surface area of the electrode (13). For this reason, screen printing is often utilized as the production method, as this technique can produce thick, uniform layers in a single pass (13, 21). Laboratory-level fabrication bar-coating with stencils has been shown to provide similar results to production-level screen printing (13) and was used in this study. Current collector sheet resistance can be correlated with equivalent series resistance (ESR) of a supercapacitor (13). This study focused only on the optimization of the printing of the current collector, rather than on assembly of complete devices. Sheet resistances were measured with the 4-point probe method (19) on a Zahner Elektrik Zennium Electrochemical Workstation over the range of -200 – 200 mV, with a scan rate of 50mV/s.

TPU sheets were cut to approximately 270mm square and wrapped—with minimal stretching of the substrate—around a 250mm square, 2.5mm-thick sheet of aluminum via 3M 810 scotch tape on the edges. This was done to ensure that the TPU stayed taut during printing, transport, and heat setting in a convection oven. A 20mm x 30mm stencil made of 120μm stainless steel was used to blade coat the graphite ink. The initial oven setting was 15 minutes at 120°C; one pass of ink was applied per current collector, as per previous settings for PET substrates (10, 13).

Initial Results

The first thirty-one test sample variants printed were unusable due to extensive topological malformation (Fig. 1). It was determined that this malformation was the result of polymer swelling caused by the 2-(2-Butoxyethoxy) ethanol 112-34-5 in the ink. Swelling occurs when a solvent enters a solid but does not dissolve it; in the case of polymers with multiple chain types, swelling may occur unevenly across the chains, creating high levels of stress at areas of cross-linking.

TPU is a block copolymer with multiple chain types and lengths, causing a highly unstructured network and morphology with

Fig. 1. Topological malformation of TPU caused by polymer swelling

both crystalline (hard, short-chain diols) and amorphous (soft, long-chain polydiols) regions with a high level of cross-linking (1, 3, 4, 6). Production method, thermal history, the level of hydrogen bonding, and chain length all affect the morphology and rheological behaviors of polymers (4). Many studies have been conducted that focus on the interactions between specific pure solvents and polymers. Results from some of these studies can be found as collected databases which can allow researchers to construct predictive theories concerning how a polymer and a mixed chemical formula containing a variety of solvents may interact (1), however, access to such a database was not available to researchers in the current study.

Thirty-one unsuccessful attempts were made to reduce the impact of the polymer swelling via substrate surface treatments or coatings, substrate heat pre-treatments, and oven heat and/or timing changes. It was found that if the ink was allowed to dwell at room temperature on the substrate prior to oven heat setting, the polymer swelling topological changes would begin to reverse. Even at a dwell time of 10 minutes, the permanent malformation after heat setting was too great for the current collectors to be used, and since dwell times of that length would be inappropriate for production-level fabrication, no additional study on dwell times was conducted. Sheet resistance measurements were taken from the nineteen (all others being too malformed for readings to be performed), with an average sheet resistance of 22 Ω/□ ±10 Ω/□. None of these samples passed the tape test with the majority of the ink film being removed.

Results

It was determined that the best method to retain the natural surface topology of the TPU was to stabilize it while printing and heat curing, in order to force the polymer chains to remain flat along the z-axis while swelling was occurring. Because the intended end-use supercapacitor electrolyte is water-based, it was known that some form of barrier would be needed to encapsulate the supercapacitors to eliminate or reduce evaporation (8, 16). Additionally, for a wearable, skin-conformable device, one side of the supercapacitor would be required to have an adhesive layer.

The stabilization method used 3M 468MP Adhesive Transfer Tape, as it is flexible and has heat resistance up to 204°C, and was successful. Samples were made by applying a 40mm x 40mm adhesive patch on the backside of the TPU in areas to be printed. This left 5mm excess tape on all sides of the printed area if perfectly centered, which was enough space to perform printing alignment by visually aligning the print when using a stencil. The TPU was secured to the aluminum sheet in the same method described above and several heat setting temperatures and times were examined, with 15 minutes at 130°C providing the lowest sheet resistance (12 Ω/□ ±7 Ω/□). Additional tests were made by adding ink passes before heat setting (two and three passes), which lowered the resistance to 7 Ω/□ ±2 Ω/□, and adding one ink pass after heat setting and then either re-heat setting with the same parameters, which raised the sheet resistance slightly (8 Ω/□ ±2 Ω/□), and at 25 minutes at 130°C which greatly lowered the resistance variability between samples (7.5 Ω/□ ±0.4 Ω/□). Samples made using these methods passed the tape test with minimal—if any—ink film being removed.

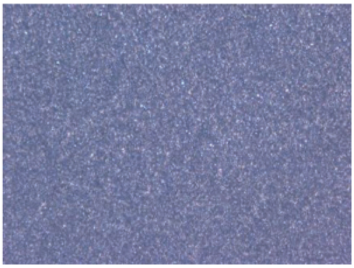

Fig. 2a) PET 5x magnification

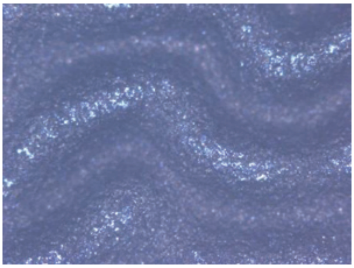

Fig. 2b) TPU with 3M ad. stabilization, 5x magnification

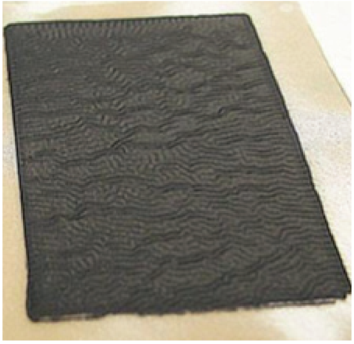

Fig. 2c) TPU with 3M ad. stabilization, no magnification (2x3cm)

In the 3M adhesive stabilized TPU samples, there is a wave pattern that appears (Fig. 2c). By comparing samples printed on PET vs. those with the wave pattern under magnification, it can be seen that the ink film thickness is uneven (IFT) (Fig. 2a and 2b). Due to lack of access to a scanning electron microscope (SEM), it is difficult to measure the variations in IFT of the wave pattern. A possible reason for the decreased sheet resistance may be that this pattern plays some role in increasing the surface area of the current collector, allowing for a faster movement of charge carriers; this type of resistance decrease has been noted in research done on nanostructured current collectors (14, 15).

Conclusion

When working with TPUs in conjunction with inks containing solvents, polymer swelling can be unpredictable and difficult to address phenomenon. However, it can also be manipulated to beneficial effect. Additional study needs to be conducted to determine if adhesive stabilization as described here is effective with other TPUs or copolymers that exhibit permanent swelling malformation, as well as determining (via SEM for example) if the wave pattern as seen is indeed creating a larger surface area, to what degree, and if there is a correlation with sheet resistance values.

A removable stabilization adhesive (3M SCPS-100 Prespacing Tape) was tested at the end of the research period[4]. There was no surface malformation of the TPU and acceptable sheet resistances (10 Ω/□ ±2 Ω/□) both before and after the stabilization layer was removed. However, due to the very small number of samples that were tested, the results were not deemed conclusive.

Drying tests were also conducted to determine how effectively the 3M tape acted as a barrier to prevent evaporation of the aqueous electrolyte. However, though it was determined that evaporation at room temperature was less than 0.002 grams over seven days with the 3M adhesive stabilization layer, tests without this layer were inconclusive, so a comparison could not be made. Without fabricating an entire supercapacitor and conducting characterization tests, conclusions as to whether the evaporation rate is acceptable would be speculative.

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CH. 2 EVALUATING HUE SHIFTS IN SPOT COLOR TINTS

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Advisors – Dr. Duncan Darby, Dr. Liam O'Hara, Robert Congdon, Dr. Samuel Ingram

Introduction

Packaging plays an important role in the modern world. It helps to preserve, protect, dispense, communicate and sell a product. Printing and color are key components of the communication and selling functions. Printing can broadly be classified into two categories on the basis combination of inks being used – process and spot color printing. Process color printing involves use of combinations of process colors – Cyan, Magenta, Yellow and Black (CMYK). Expanded gamut printing is a special case of process printing where additional colors, typically orange, green and violet, are used to achieve a larger color gamut. Spot color printing uses specially formulated inks that are designed to achieve a particular color appearance on a given substrate. The brand colors as commonly printed as spot colors. Different brands use characteristic colors that the consumers can relate to their products and brand identity e.g. a coca cola red or a Pepsi blue. Color can be defined using colorimetric coordinates in a 3-Dimensional (3D) CIELAB space. The L* represents lightness or darkness, a* stands for redness or greenness and b* indicates the yellowness or blueness of a color. These colorimetric coordinates can also be represented in CIELCH space using L*C*h° values, where C* is the chromaticity and h° represents the hue angle of a color. Studies have suggested a higher visual sensitivity towards hue as compared to saturation and lightness (Danilova & Mollon, 2016) (Durmus & Davis, 2019).

The standard colorimetric values for solids of spot colors are well defined by either Pantone specifications, L*a*b*C*h° values, spectral data, or with a combination of these. However, the spot color halftones or tints are commonly managed using tone value and dot gain. Spot Color Tone Value (SCTV) is the preferred metric used to measure tone values of spot colors. The presence of tonal data standards for spot colors would help in soft proofing, digital contract proofs and managing the colorimetric expectations from design to the print production stages (O'Hara, et al., 2014). However, the colorimetric appearance of spot color tints are difficult to predict and standardize. The extraction, simulation, and prediction of spot color tints solely on the basis of spot color solids can be problematic and presents accuracy challenges (Washington, DC: U.S. Patent and Trademark Office Patent No. 7,612,926, 2009) (Cory, Roesch, & Specht, 2017). A recommendation to address this problem of communication and consistency of spot color

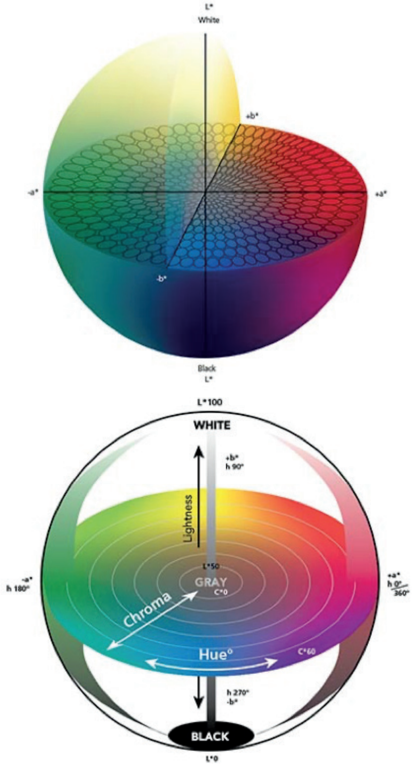

Fig. 1. Colorimetric coordinates in CIELAB and CIELCH models (Mouw, 2018)

tint information was provided in ISO 17972-4 (2018). The standard provided guidelines on exchange of spot color characterization data. The standard suggested the use of spectral reflectance data and opacity to characterize spot color inks. The conformance level CxF-4a required spectral characterization with at least 11 patches (including tints) of spot color ink on a single substrate. However, the standard does not completely address some concerns that are typical to printing of spot color tints and overprint. Some spot colors are known to exhibit a hue shift as the printed tone value decreases. A common example of such a color is Reflex Blue, which tends to shift towards a purple hue as the tone value decreases. The tendency of this shift may depend upon different factors such as the hue itself, ink recipe, tone value and or the substrate. Figure 2 shows the hue shift in printed tint results compared to the reference hue corrected line. The hue corrected line consists of the same L*C* value as the printed tints, but the hue angle is replaced by the hue angle of the solid.

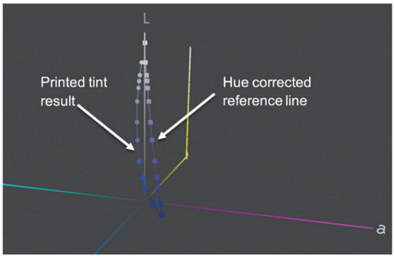

Fig. 2. Print and hue corrected curves for PReflex Blue-FWCP in CIELAB space

The potential primary factors affecting and/or contributing to these hue shifts are ink characteristics (lightness, chromaticity, hue, spectral curve shape), differences in ink recipe, printed tint percentage and the substrate effects. The nature and extent of these hue shifts in some spot colors could be difficult to predict or reproduce every time, especially if any of the critical factors mentioned before are changed. Moreover, these inks can be mixed using various possible combinations of the different base pigment inks. Different ink manufacturers may use different ink recipes and base pigments for making the same spot ink if a spectral match is not required. While this approach may work well for achieving a color match in the solids, halftones may show differences in hue for the differently formulated inks (O'Hara, et al., 2014). These color shifts may be more apparent in case of spot color overprints. This also presents a decision point in conversion of spot color tints to Expanded Color Gamut (ECG) separations. The question to be answered here is should the ECG separation simply reproduce the results observed while printing a true spot color ink or aim to adjust and correct this hue shift. As seen in the image below (obtained from Mark Samworth – Esko Graphic Inc. (2018), the spot color printed to linear SCTV shows hue shift towards purple hue. The other two variants are Esko Equinox converted renditions of the same color, printed with and without linearizing to SCTV.

Even if the hue shift is accurately matched to the reference print output with a specific ink formulation, it may not necessarily align with the designer and brand owner's perception and preference of the desired color appearance. If the digital view of the spot color tints is not accurately represented in the prepress software solutions, there can be a gap between the designer or a brand owner's view and the printed results. Color accurate visual representation of tint or overprint is not supported in many software solutions (Cory, Roesch, & Specht, 2017). There are, however, few pre-press software solutions that help in simulating the spot color tints in proofing environment. This study uses the PantoneLIVE dependent library data as a digital standard. This study focuses on using three different hue shift metrics to characterize the extent and nature of hue shifts in spot color tints. The maximum hue shifts and the corresponding SCTV will be noted. The study is also intended to address how different these hue shifts are from a digital reference commonly used by designers . The three metrics used to characterize hue shift will also be compared with each other.

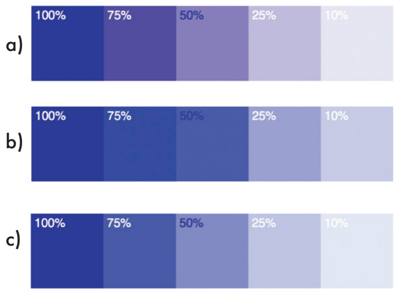

Fig. 3. Three variants of Reflex Blue

a) Spot Color – Reflex Blue – Printed on Press to Linear SCTV

b) Esko Equinox converted Reflex Blue – Printed on Press – No curve correction

c) Esko Equinox converted Reflex Blue – Printed to Press – Corrected to Linear SCTV

Images courtesy of Mark Samworth – Esko Graphic Inc.

Scope of the Study

The study was limited to six spot colors on a single paperboard packaging substrate. The study was conducted with water-based inks as these are common for paperboard packaging. PantoneLIVE dependent library Flexo Water-Based Coated Paper (FWCP) was used as a digital reference. Other software solutions, although available, were not evaluated under this study. The substrate was chosen based on substrate in the PantoneLIVE FWCP library.

Experimental Design

The input variables included six different spot colors, a range of tonal values and two different ink recipes for one of the six spot colors. The selection method and standard values for each color are described in the ink section of methods and materials. The two different ink recipes for the color P4975-FWCP were used to evaluate the effect of different ink recipes on hue shift behavior. The tone scale from 10% to 100% was printed at increments of 10% (with addition of 25%, 50% and 75% patches). The tone scales were printed for all the colors over paper, over a printed black background and in randomized order. The print over black was conducted for opacity calculations, if needed in the future. The patches were also printed in randomized order in case any process bias was recognized in the data. The test chart design and components can be seen in the test chart section of the methods and materials section.

In terms of the output metrics, this study involved quantification of hue shift with three different metrics. ASTM D2244 stated that the difference in hue angle between a sample and specimen could be correlated to the differences in visual perception of these hues, with an exception of very dark colors (ASTM, 2016). Hence, a difference between hue angles of solid and the tints (Δh_{ab}) was used as the first metric. The calculations were corrected for hue angle shift between quadrants e.g. hue angle moving from 359° to 1°. This metric is referred to as 'hue angle difference' in this study. The second metric used in this study was the hue difference called Delta H (ΔH^*_{ab}). The formula used for calculations was selected based on ISO 11664-4 (2019) recommendations.

$$\Delta H^*_{ab} = 2(C^*_{ab,1} \bullet C^*_{ab,0})^{0.5} Sin(\frac{\Delta h_{ab}}{2})$$

where, ΔH^*_{ab} = Delta H or Delta hue as a measure of hue difference

C^* = Chromaticity = $(a^{*2} + b^{*2})^{½}$

$C^*_{ab,0}$ = Chromaticity of test (tint)

$C^*_{ab,1}$ = Chromaticity of solid reference

$\Delta h_{ab} = h_{ab,1} - h_{ab,0}$ = *Hue Angle Difference = Hue angle of solid - Hue Angle of tint*

While the hue angle difference (Δh_{ab}) as an individual metric was calculated and analyzed in degrees, the hue difference (ΔH^*_{ab}) formula requires the (Δh_{ab}) to be in radians.

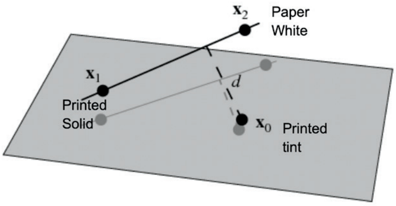

Fig. 4. Paper white point (X2), solid point (X1) and tint (X0) of spot color plotted in three-dimensional (3-D) space (Weisstein, 2020)

A new metric was also developed in this study to characterize hue shift. The third metric used in the study was the shortest distance between the tint and a line joining paper white point and the solid in a CIELAB space. To understand the orthogonal distance calculation, please refer to Figure 4. Here

X_1=L*a*b* coordinates of solid = (L_1, a_1, b_1)

X_2=L*a*b* coordinates of paper = (L_2, a_2, b_2)

X_0=L*a*b* coordinates of tint = (L_0, a_0, b_0)

The shortest distance between the point X_0 and the line connecting the solid to the paper white point in 3D space is represented by the orthogonal distance between the point X_0 and line vector ($\overrightarrow{X_1 X_2}$). This distance is calculated using the formula below:

$$d = \frac{|(X_2 - X_1) \times (X_1 - X_0)|}{|(X_1 - X_0)|}$$

where, $|(X_2 - X_1) \times (X_1 - X_0)|$ is the magnitude of the cross product of the two terms and

$|(X_1 - X_0)| = \sqrt{(L_1 - L_0)^2 + (a_1 - a_0)^2 + (b_1 - b_0)^2}$

which is the magnitude of the substraction of vector X_0 from X_1 (Weisstein, 2020).

The input variables and their corresponding levels along with the output variable and corresponding metrics are summarized in Table 1.

Methods and Materials

Substrate

The study was conducted on Westrock 12 point (pt) PrintKote paperboard substrate. This paper was selected in accordance to the white point of the PantoneLIVE digital library used as a reference in this study. Paperboard substrate is widely used in packaging applications.

Inks

Paperboard substrates are commonly printed with water based inks for a wide variety of

Input Variables	Levels
Color	6 Spot Colors – Red (P485-FWCP), Green (P357-FWCP), Blue (PReflex Blue-FWCP), Orange (POrange021 – FWCP), Purple (P261-FWCP), and Brown (P4975-FWCP)
Ink Recipe	2 ink recipes with different base pigments
Tone Value	11 levels – 10, 20, 25, 30, 40, 50, 60, 70, 75, 80 and 90%
Output Variables	**Metrics**
Hue Shift	Hue Angle Difference (Δh_{ab}), Hue Difference of Delta H (ΔH^*_{ab}), Orthogonal Distance (OD)

Table 1. Summary of input and output variables with corresponding levels and metrics

packaging applications, mainly in the food industry. The colors of the inks for this study were selected based on the data collected from a preliminary press run, PantoneLIVE data, and spot color usage statistics. The colorimetric data from the preliminary study involving six different spot colors was analyzed for hue shift across the tonal range. The six spot colors printed in the preliminary study were P135C (light yellow), P2706C (light blue), P1485C (light orange), P187C (dark red), P357C (dark green), and P2685C (dark violet). Hue angle difference and Delta H were used as metrics. This data is presented in Figure 5.

The data suggested that the maximum hue angle difference of more than 10 degrees was observed in the spot color tints for colors Pantone P187 (dark red) and Pantone P2685 (dark violet). The Delta H data agreed with the hue angle difference data with a more distinct differentiation between high and low hue shift colors. The data from this study suggested higher hue shift in darker and more chromatic colors than lighter colors. The highest hue shifts were seen in the red and violet regions. It should be noted that the data from the preliminary study was collected under M1 measurement mode while the all the data collected in the current study was collected in M0 measurement

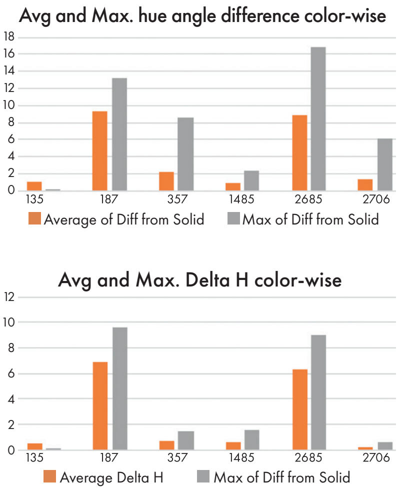

Fig. 5. Absolute average and maximum hue angle difference and Delta H data from preliminary study

mode. The preliminary data was only meant to serve as a precursor to the actual study and no direct comparisons were drawn between this data and the data collected under the current study.

PantoneLIVE library provides the colorimetric information for spot color tints in addition to the solids. The top twenty-five most used spot colors from the usage statistics were selected and their colorimetric data, including tints, was extracted from the PantoneLIVE Library. The data were analyzed for hue angle difference. Colors showing a maximum hue angle difference of more than 10 degrees across the tonal range were selected for this study. The PantoneLIVE dependent library - Flexo Water-Based Coated Paper (FWCP) library was used in this study. The colors were also segregated based on their hues and only one color from a segment was selected i.e. one color each from orange, red, purple, blue, and green regions. The inks in Table 2 were selected for the print trials based on the conditions mentioned above. The maximum hue shift and the corresponding spot color tone value (SCTV) data from PantoneLIVE – FWCP library are also listed below.

Color	Maximum Hue Angle Difference (degrees)	Spot Color Tone Value at maximum hue angle difference
P357-FWCP (Dark Green)	19.38	17.58 %
P261-FWCP (Purple)	-19.44	18.13 %
POrange021-FWCP (Orange)	15.17	18.01 %
P4975-FWCP (Brown)	-57.79	16.01%
P485-FWCP (Red)	10.90	33.92 %
PReflex Blue-FWCP (Blue)	9.56	24.96 %

* Hue angle data for SCTV below 15% was excluded due to abnormally high observations.

Table 2. Target colors, maximum hue angle difference and corresponding SCTV from PantoneLIVE data

For simplicity reason, the spot colors may be used without the FWCP suffix in this report. The inks were formulated and donated by an ink manufacturer. However, the reflex blue ink was reformulated with the Xrite Ink Formulation Software v6 using an ink recipe suggested by ink company's color matching experts. The inks viscosity and pH were measured but left unadjusted to avoid any changes in the hue angle due to dilution.

Test Chart

The test chart consisted of tonal patches of the 6 inks arranged along machine direction and cross-direction. A randomized chart with the same patches was also included in the target. The layout of the test chart is as shown below.

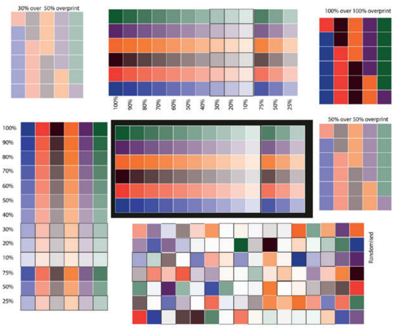

Fig 6. Test Chart Layout

Print Setup and Run

The plate files were launched though workflow, arranged and imaged using Esko Automation Engine, Merger and Exposer software. Dupont EPR 067 photopolymeric plates were made on an Esko Crystal Cyrel Digital Imager (CDI) and XPS system. The plates were solvent processed, dried, and post-exposed and light-finished on an Evo 3A machine. The plates were output with a linear curve without any compensation curve applied. However, a 2 to 1 bump curve was applied to the file while launching the workflow. A 120 lpi screening was applied to all the plates and the Esko crystal CDI resolution was set to 4000 dpi. The print trials were conducted on an Omet Varyflex 7 color press at 150 feet-per minute (fpm). The first station was used for printing black and the rest six stations were used to print six different spot color inks. The impression settings were set at minimum impression. The ink sequence and the anilox used for each station are listed in Table 3.

Station No.	Ink	Anilox Configuration
1	Process Black	500 lpi/5.0 bcm
2	Pantone 357	900 lpi /2.2 bcm
3	Orange 021	800 lpi/2.8 bcm
4	Pantone 261	600 lpi /4.0 bcm
5	Pantone Reflex Blue	500 lpi /4.0 bcm
6	Pantone 485	800 lpi /2.8 bcm
7	Pantone 4975	900 lpi /2.2 bcm

Table 3. Ink sequence and anilox setup used

The Delta E_{00} tolerance was set at 5.00 due to anilox availability limitation and inks being formulated to a standard ink film thickness. However, the Delta H tolerance was kept under 2.5 for all colors. Xrite-Colorcert software was used for achieving and monitoring color on the press. The standard and the measured print results during setup are mentioned in Table 4.

Data Collection

Fifteen sheets were randomly selected from the printed roll and measured. The measurements were taken with an Xrite eXact Standard + Scan instrument using the Xrite DataMeasure tool. Measurements were taken in M0 mode as the PantoneLIVE data was available in M0 mode. The measured tristumuls values and L*a*b* values were used to calculate SCTV, and chroma and hue values. The data from printed sheets were averaged over fifteen sheets for each color. The average hue angle and hue shifts of fifteen sheets per color were used for drawing graphs and corresponding inferences. The measurements for patches under 15% SCTV were disregarded as these showed abnormally high hue shifts. This can be attributed to the proximity to the achromatic axis and significant show-through effect from the paper.

Results and Discussion

The hue angle difference, Delta H and orthogonal distance were plotted against the measured SCTV value for all the printed colors. The curve shapes for each metric were compared between the digital reference (PantoneLIVE data) and the print output. The extent of difference between maximum hue shift for print and maximum hue shift for PantoneLIVE were used to judge the similarity. Moreover, the maximum hue shift shown in the print and PantoneLIVE data should be in the similar tonal range (either both in highlight, midtone or shadows) for the curves to be termed similar. The plotted curves were also examined for the trends in

Color	Standard	Print Result	Deltas	
P357-FWCP	L: 33.96 a: -23.08 b: 13.06 C: 26.52 h: 150.50	L: 32.28 a: -28.82 b: 11.17 C: 30.91 h: 158.82	L: -1.24 a: -1.03 b: 0.16 C: 0.98 h: 8.32	E_{00}=3.39
P261 - FWCP	L: 26.53 a: 31.83 b: -22.33 C: 38.88 h: 324.95	L: 21.39 a: 26.77 b: -17.51 C: 31.99 h: 326.81	L: -5.14 a: -5.06 b: 4.82 C: -6.89 h: 1.86	E_{00}=4.63
POrange 021 - FWCP	L: 62.71 a: 57.65 B: 73.79 C: 93.64 h: 52	L: 64.96 a: 53.30 b: 74.09 C: 91.27 h: 54.27	L: 2.26 a: -4.35 b: 0.30 C: -2.37 h: 2.27	E_{00}=2.75
P485 - FWCP	L: 50.43 a: 61.13 b: 47.18 C: 77.22 h: 37.66	L: 47.85 a: 66.33 b: 48.54 C: 82.19 h: 36.20	L: -2.59 a: 5.20 b: 1.37 C: 4.98 h: -1.46	E_{00}=3
PReflex Blue - FWCP	L: 24.01 a: 30.22 b: -62.47 C: 69.40 h: 295.81	L: 20.91 a: 29.81 b: -66.06 C: 72.48 h: 294.29	L: -3.1 a: -0.41 b: -3.59 C: 3.08 h: -1.52	E_{00}=2.86
P4975-FWCP – Recipe 1	L: 20.07 a: 6.94 b: 3.19 C: 7.64 h: 24.69	L: 20.01 a: 14.14 b: 6.69 C: 15.64 H: 25.32	L: -0.06 a: 7.19 b: 3.50 C: 8.00 h: 0.66	E_{00}=6.42
P4975-FWCP – Recipe 2	L: 20.07 a: 6.94 b: 3.19 C: 7.64 h: 24.69	L: 23.27 a: 5.62 b: 2.59 C: 6.19 H: 24.77	L: 3.20 a: -1.32 b: -0.60 C: -1.45 h: 0.08	E_{00}=2.67

Table 4. Colorimetric standard and printed values for each color with color differences (Deltas)

hue shift and the tonal areas most susceptible to hue shift. The maximum hue shift was also noted and compared between the tested colors.

Figure 7 shows the hue angle difference in the measured printed samples. The general trend suggested an increase in hue angle difference as the measured SCTV decreased. P261 and P357 showed maximum hue shifts below 10 degrees between 30% and 50% SCTV. The most significant hue shift was seen in P4975. This was followed by PReflex Blue, POrange 021 and P485. P4975 distinctively stood out from this image. This color showed a high negative hue angle difference which changed to positive at approximately 30% SCTV and above. This was due to the low chromaticity of the color and proximity to the achromatic axis. Even small changes in a* and b* values can show high hue shifts near the achromatic axis.

An overview of Delta H is presented in Figure 8. Unlike the hue angle difference graph, a clear distinction can be seen between two sets of colors. While some colors showed Delta H close to 0 throughout the tonal range, few colors showed Delta H around 10 in the midtone region. The curve shape for Delta H was also different than the curve shape for hue angle difference. An increase in Delta H can be seen as the SCTV approaches midtone from either end of the tone-scale. The colors showing a low maximum Delta

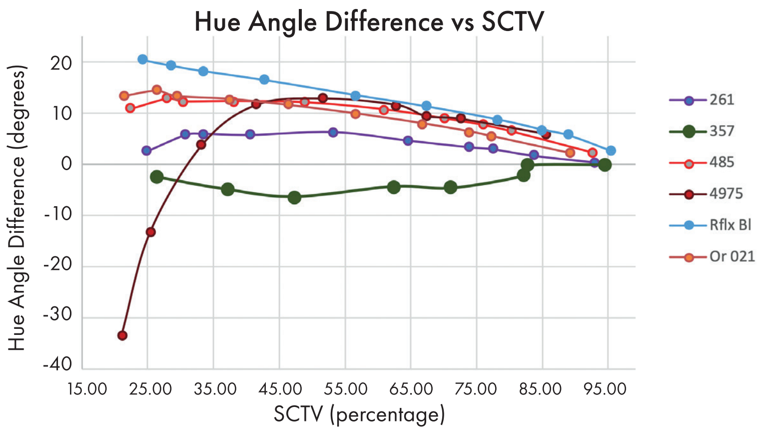

Fig. 7. Overview of hue angle difference data versus measured SCTV in print

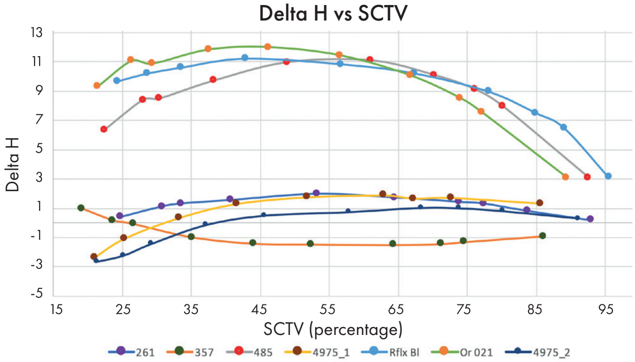

Fig. 8.
Overview of Delta H data versus measured SCTV in print

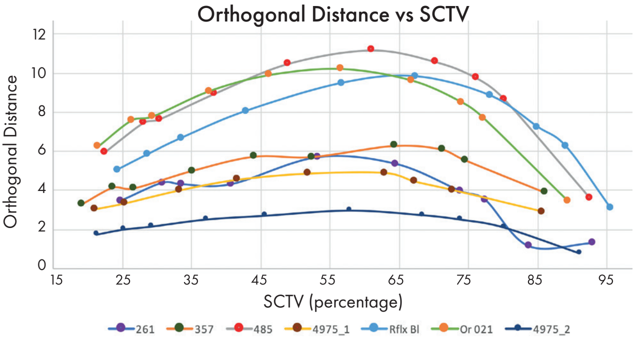

Fig. 9.
Overview of orthogonal distance data versus measured SCTV in print

H, between 3 and -3, are P261, P357, P4975-1C (P4975 printed with ink recipe 1) and P4975-2 (P4975 printed with ink recipe 2). The color P4975 showed low Delta H despite showing a high hue angle difference. This was due to the chromaticity scaling incorporated in the Delta H calculation. The colors P485, PReflex Blue and POrange021 showed maximum Delta H of more than 10. The curve for these colors have a characteristic shape where the highest Delta H is seen in the midtones.

Figure 9 presents the orthogonal distance results in graphical form. While the colors P261, P357, P4975-1 and P4975-2 showed low orthogonal distances, the colors P485, PReflex Blue and POrange021 showed maximum orthogonal distance above 10. The curve shape resembled that of Delta H where the orthogonal distance increases and showed peak in the midtones.

The hue angle difference, Delta H and orthogonal distance results are presented and discussed for each color below. The L*a*b* values from the print measurements were plotted in CIELAB color space using ColorThinkPro v3.0.7. Another series was added to the ColorThink plots as the hue corrected series. The hue corrected series contains the same L*C* values as the printed tints, but the hue angle was kept the same as the solid. This series was used to serve as a reference to visually highlight the hue shift seen in the printed results. The print data series can be identified by spherical shaped points while the hue corrected data series is represented by cube shaped data points (Refer Fig. 2 for labeled figure).

The print and hue corrected lines for P261-FWCP data did not show a noticeable hue shift.

The maximum hue angle difference for P261 – Print was approximately 6 degrees while for PantoneLIVE data, the maximum was around -10 degrees. The nature of hue angle difference and Delta H predicted by the PantoneLIVE data is not very well replicated in the print. The PantoneLIVE data shows the hue angle difference and

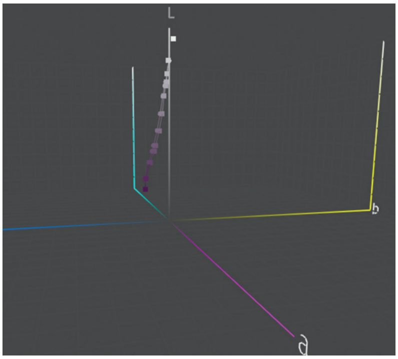

Fig. 10. Print and Hue Corrected data for P261-FWCP in CIELAB space

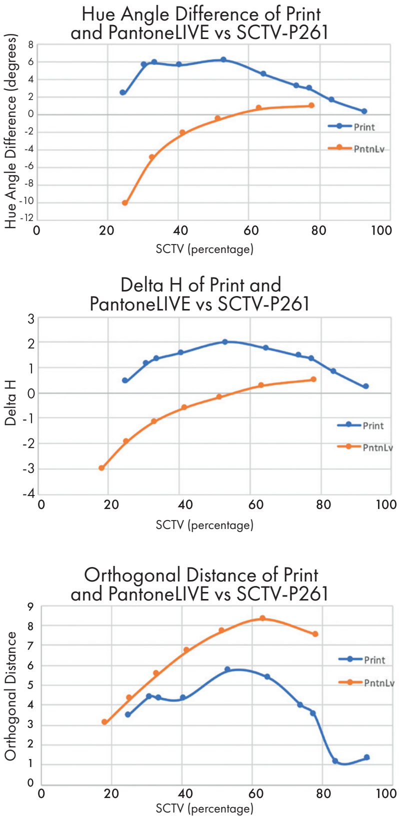

Fig. 11. Hue angle difference, Delta H and Orthogonal Distance curves from Print and PantoneLIVE data for P261 - FWCP

Delta H to be increasing with decrease in SCTV. On the other hand, the print data reaches maximum hue angle difference and Delta H at 50% SCTV and reduces as the SCTV increases or decreases from there. This behavior was more distinctly seen with Delta H metric than the hue angle difference. While the curve for print showed a positive shift, the PantoneLIVE data curve suggested a negative hue angle difference and Delta H below 50% SCTV. The curve shape for PantoneLIVE data showed an almost linear increase in Delta H as the SCTV reduced. The orthogonal distance showed the same curve shape for print as hue angle difference and Delta H with maximum distance at 50%. The curve shape for the PantoneLIVE data also agreed with the other metrics, except that a peak was seen at around 65% SCTV. The orthogonal distance curve from print was similar to the PantoneLIVE curve.

The print and hue corrected lines for P357-FWCP data did not show any noticeable hue shift.

The observed hue angle difference and Delta H in print was significantly lesser than

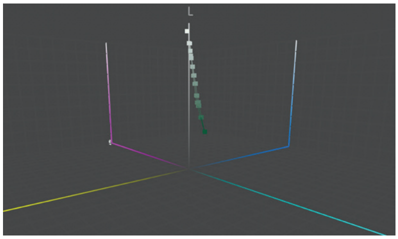

Fig. 12. Print and Hue Corrected data for P357-FWCP in CIELAB space

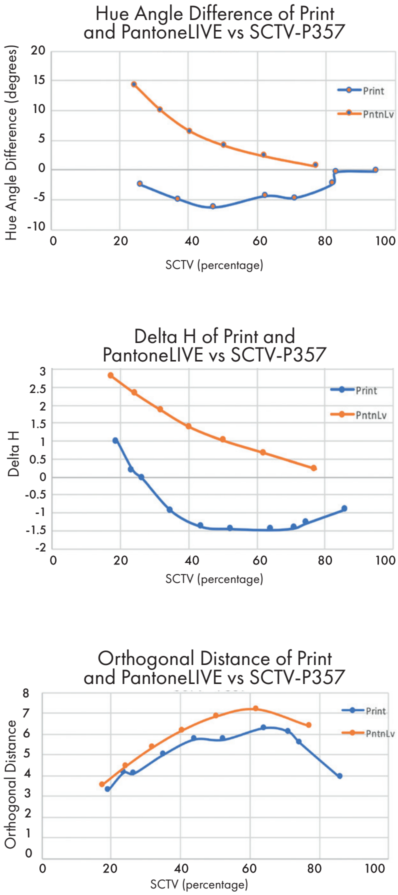

Fig. 13. Hue angle difference, Delta H and Orthogonal Distance curve data from Print and PantoneLIVE FWCP library for P357

the PantoneLIVE predictions. While the maximum hue angle difference and Delta H were observed around 50% SCTV in print, the maximums were observed around 25% SCTV for PantoneLIVE data. The hue angle difference and Delta H curve shapes were different for print and PantoneLIVE. The PantoneLIVE data showed an increase in these metrics as SCTV reduced, while the print data showed a maximum at around 50% SCTV and reduced on either side of the tone scale. Moreover, the PantoneLIVE data showed positive hue angle difference and Delta H, while the print data showed hue angle difference and Delta H in the opposite direction. Unlike the other metrics, the orthogonal distance curves for print and PantoneLIVE appeared similar. The maximum orthogonal distance was observed between 60% and 65% SCTV for both, print and PantoneLIVE.

The print and hue corrected lines for P485-FWCP data showed a noticeable hue shift. The hue shift curve suggested highest hue shift in the midtone region with decreasing shift towards highlights and solids.

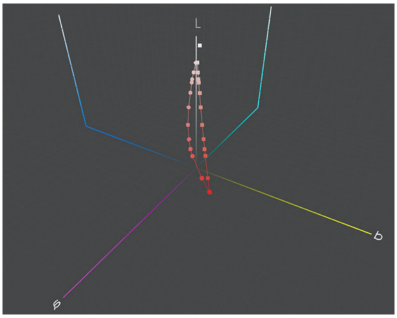

Fig. 14. Print and Hue Corrected data for P485-FWCP in CIELAB space

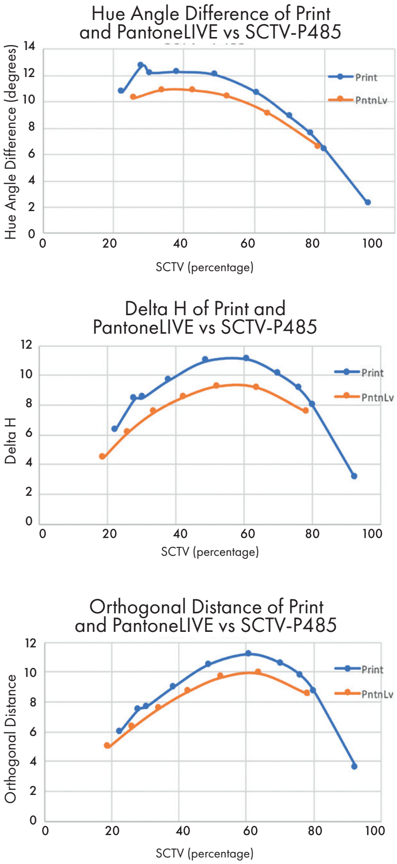

Fig. 15. Hue angle difference, Delta H and Orthogonal Distance curve data from Print and PantoneLIVE FWCP library for P485

The hue angle difference for print and PantoneLIVE showed similar curve shape and amplitude of shift. The hue angle difference curves went through peak between 30 and 40%. The Delta H curves for print and PantoneLIVE data showed peaks at around 55%. A good approximation of print was seen with the PantoneLIVE data in terms of curve shape and extent of Delta H and orthogonal distance. The maximum hue angle difference was higher than 10 degrees for print and PantoneLIVE data of P485 – FWCP. The orthogonal distance curves for print and PantoneLIVE also appeared similar with the peak on both curves between 60 and 65% SCTV.

The print and hue corrected curves for PReflex Blue-FWCP data showed a noticeable hue shift. The hue shift curve suggested highest hue shift in the midtone region with decreasing shift towards highlights and solids.

The hue angle difference for print and PantoneLIVE data of PReflex Blue showed similar curve shapes but a large difference in extent of hue shift. The curve trend suggested an increase in hue angle difference as SCTV

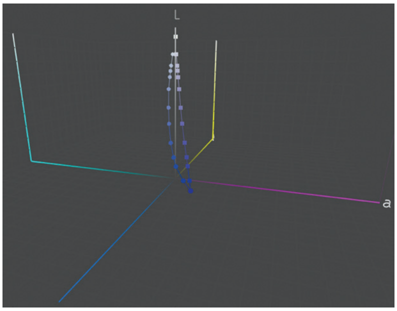

Fig. 16. Print and Hue Corrected data for PReflex Blue-FWCP in CIELAB space

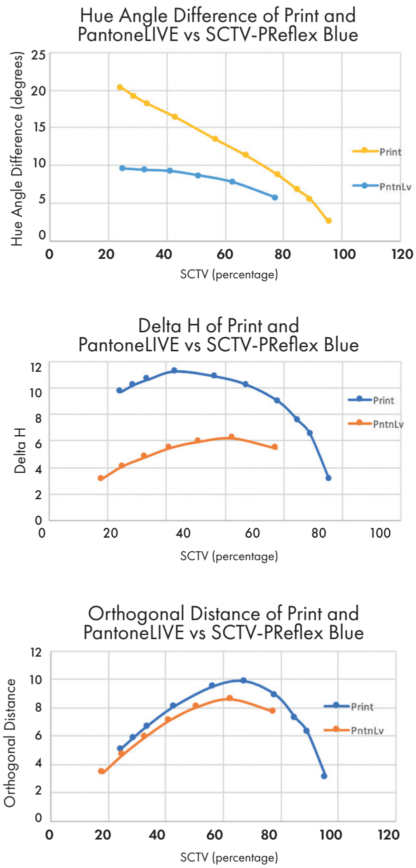

Fig. 17. Hue Angle Difference, Delta H and Orthogonal Distance data from Print and PantoneLIVE FWCP library for PReflex Blue

reduced. This increase was more pronounced in print data when compared to PantoneLIVE data. The maximum hue angle difference for both the data was observed at around 22% SCTV. The Delta H curve shapes were different for the print and PantoneLIVE data. While the print data showed peak in the highlights, the PantoneLIVE data suggested maximum Delta H in the midtone region. A decrease in Delta H was observed as the SCTV moved in either direction from these peaks. The orthogonal distance data for Print and PantoneLIVE data showed similar curve shapes . The orthogonal distance curve shape suggested a peak in the midtone region and a decrease as the SCTV moved in either direction.

The print and hue corrected curves for POrange021-FWCP data showed a noticeable hue shift. The hue shift curve suggested highest hue shift in the midtone region with decreasing shift towards highlights and solids.

The hue angle difference, Delta H and the orthogonal distance curves for print and PantoneLIVE data of POrange 021 showed similar shape and extent of shift.

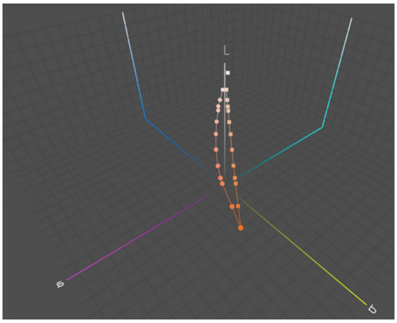

Fig. 18. Print and Hue Corrected data for POrange021-FWCP in CIELAB space

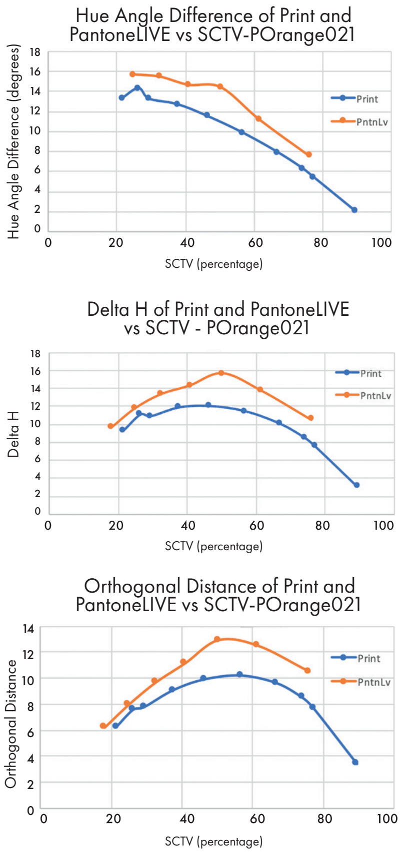

Fig. 19. Hue Angle Difference, Delta H and Orthogonal Distance data from Print and PantoneLIVE FWCP library for POrange 021

The trend suggested an increase in hue angle difference as the SCTV reduced. The hue shifts predicted by PantoneLIVE data were slightly higher than that observed in the printed samples. Unlike the hue angle difference data, the peak Delta H and orthogonal distance for print and PantoneLIVE data were observed between 40% and 60% SCTV. The metrics showed a decrease as the SCTV moved above or below that range. Overall, the PantoneLIVE data predicted the print hue shift performance well for this color.

The print and hue corrected lines for both recipes of P4975-FWCP data did not show a noticeable hue shift in CIELAB plot. On comparing the two recipes with each other, a similar hue shift behavior was observed between them.

The plots for P4975 contain three data series – print from ink recipe 1, print from ink recipe 2 and the PantoneLIVE data. The hue angle difference curves for P4975 – FWCP are significantly different for prints and the PantoneLIVE data. The hue angle difference curve for PantoneLIVE suggested

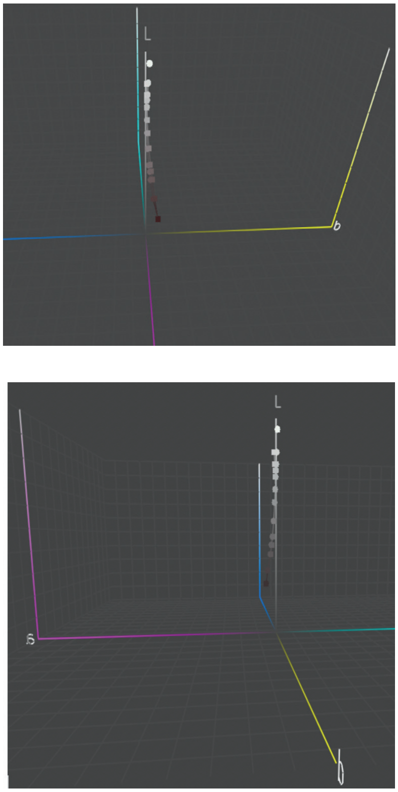

Fig. 20. Print and Hue Corrected data for P4975-FWCP in CIELAB space a) Recipe 1; b) Recipe 2

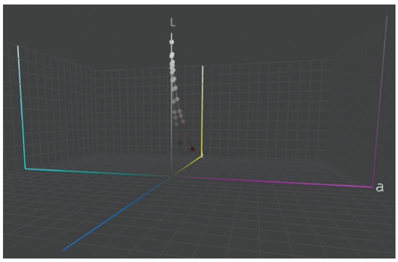

Fig. 21. Print data for the two recipes of P4975-FWCP in CIELAB space (series on the outside represents recipe 1 and the other is recipe 2)

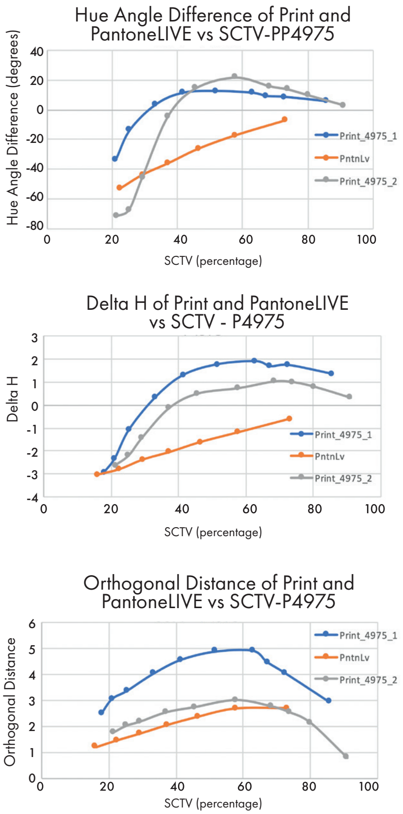

Fig. 22. Hue angle difference, Delta H and Orthogonal distance data from Print and PantoneLIVE FWCP library for P4975

a linear negative increase in hue angle difference with a decrease in SCTV. On the other hand, the print data followed a curve showing sharp knee-shaped change in hue shift around 40% SCTV. The maximum hue angle difference was observed at 20% tone value for both the prints and the PantoneLIVE data series. The print curves show the hue angle difference moving from negative to positive between 30 and 40% SCTV. This change in sign can be attributed to the low chromaticity of the color. Since the points were close to the achromatic axis, small shifts in the CIELAB space caused large shifts in the hue angle.

The Delta H for print data from both the ink recipes showed similar curve shape with maximum hue shift between 60% and 70% SCTV. However, the Delta H curve shape for PantoneLIVE data was different than that for the print data. The magnitude of hue shift suggested by Delta H metric was much lower than that seen in hue angle difference. This was due to the chromaticity scaling included in the Delta H formula and low chromaticity of P4975-FWCP. The Delta H curves for PantoneLIVE showed a straight line indicating a linear negative increase in magnitude of hue shift with decrease in SCTV.

The orthogonal distance curve for print- recipe 2 was much closer to the PantoneLIVE prediction than the ink recipe 1 results. It is worth noting that the chromaticity of print with ink recipe 2 was much closer to the PantoneLIVE standard than the ink recipe 1.

The ink recipe 1 showed higher orthogonal distance than the ink recipe 2 and PantoneLIVE. The orthogonal distance curve shapes for both the ink recipes showed similar shapes with a maximum hue shift around 60% SCTV.

While comparing the two ink recipes, the hue angle difference curve shapes were not similar, but the Delta H and orthogonal distance curves were similar in shape. The Delta H curve showed difference in extent of hue shift between the two recipes. The three metrics unanimously showed higher hue shift for ink recipe 1 than for ink recipe 2. It is worth noting that the L* and ho values for both the recipes was similar. However, the C* for printed solid with ink recipe 1 was 15.64 while that for ink recipe 2 was 6.19. This supports the finding that higher chromaticity resulted in a higher hue shift.

The efficacy of the three metrics in characterizing the hue shifts for print and PantoneLIVE data was evaluated. For each metric, the absolute value of difference between maximum hue shift for print and PantoneLIVE was calculated. The calculation is defined as:

$$\text{Maximum hue angle difference between print and PantoneLIVE data} = \left| \begin{matrix}\text{Max } \Delta h_{ab} \\ \text{for print data}\end{matrix} - \begin{matrix}\text{Max } \Delta h_{ab} \\ \text{PantoneLIVE data}\end{matrix} \right|$$

This difference was used as an indicator of how each hue shift metric performed in terms of predictability of print with PantoneLIVE data. A higher difference indicates poor predictability for that metric.

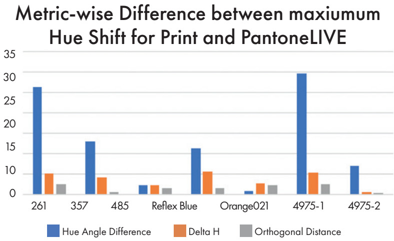

Fig. 23. Maximum difference between hue shift metrics for Print and PantoneLIVE data

The image above clearly shows that hue angle difference showed the highest difference between the print and PantoneLIVE data. The lowest difference was seen with the orthogonal distance. The difference for Delta H lied between hue angle difference and orthogonal distance. The limitation of hue angle difference as a hue shift metric were highlighted with low chromaticity color i.e. P4975-FWCP. The metric overestimated the hue shift and showed sign changes as well. Orthogonal difference showed the closest results to the PantoneLIVE data. In terms of predictability of print results with PantoneLIVE data, orthogonal difference appeared to be a better metric than the rest. However, orthogonal distance is a strictly positive quantity and does not indicate the direction of shift. On the basis of observations from the CIELAB plots and the individual metric curves, Delta H appeared to the best metric in terms of distinguishing between low and high hue shift colors.

Summary of Results

Hue Shift Behavior

Based on the results of preliminary and main study, the hue shift behavior was observed to be higher for colors with high chromaticity. The yellow hue region showed negligible hue shifts, while the violet, red, orange and reflex blue hues showed a noticeable hue shift.

The colors ranked in decreasing order of maximum hue angle difference in print are – P4975- Recipe 2 , P4975- Recipe 1, PReflex Blue, POrange021, P485, P261, P357.

The colors ranked in decreasing order of maximum Delta H in print are – POrange021, PReflex Blue, P485, P4975- Recipe1, 4975- Recipe2, P261, P357

The colors ranked in decreasing order of maximum orthogonal distance in print are – P485, POrange021, PReflex Blue, P357, P261, P4975- Recipe1, P4975- Recipe2

Print versus Digital (PantoneLIVE) Comparison

The print and PantoneLIVE curves for different hue shift metrics were examined for similarities and the data is summarized in Table 5.

	Similar	Dissimilar
Hue Angle Difference	P485, POrange021	P261, P357, PReflex Blue, P4975 -1, P4975 -2
Delta H	P485, POrange 021	P261, P357, PReflex Blue, P4975 -1, P4975 -2
Orthogonal Difference	P261, P357, P485, POrange021, PReflex Blue, P4975-1, P4975 -2	

Table 5. Hue Shift metric-wise summary of similar and dissimilar colors (Print vs PantoneLIVE curves)

The data presented in Table 5 suggests that the colors P485 and POrange 021 showed similar hue shift behavior and extent between print and PantoneLIVE data. Orthogonal distance as a hue shift metric showed better correlation with the PantoneLIVE data than the other two metrics.

Effect of different ink recipe

The hue shift behavior for the two ink recipes of P4975-FWCP was similar. However, the extent of hue shift was shown to be higher in printed with recipe 1 than with recipe 2. This was attributed to the higher chromaticity of the print with recipe 1 than with recipe 2.

Comparison of Metrics

Hue angle difference showed limitations for colors close to the achromatic axis. Hue angle difference was observed to increase with a decrease in SCTV while the Delta H and orthogonal distance showed peaks in the midtone region. The hue shift behavior seen in Delta H and orthogonal distance plots was similar to that seen in CIELAB plots of the print data.

Conclusion

The nature and extent of hue shift for tints of six spot colors were characterized using three hue shift metrics. The study showed that colors with high chromaticity showed higher hue shifts than spot colors with lower chromaticity. The hue shift , as suggested by Delta H, orthogonal difference and CIELAB plots, was observed to be the highest in the midtone region. Spot color tints of P485, PReflex Blue, and POrange 021 showed noticeable hue shift while the colors P261, P357 and P4975 did not show significant hue shifts. The print and PantoneLIVE data for P485 and POrange 021 showed similar hue shift behaviors and magnitude. Orthogonal distance as a hue shift metric showed better correlation between print and PantoneLIVE data than the other two metric. Hue angle difference as a hue shift metric can exaggerate hue shifts while characterizing low chromaticity colors near the achromatic line. Delta H was the most successful metric in showing the distinction between high and low hue shift colors. The two ink recipes for P4975 did not show a significant difference in hue shift behavior. But, it is recommended to repeat the different ink recipe exercise with a higher chromaticity spot color.

Further Study

This study evaluated the hue shift in spot color tints with three different metrics. A visual analysis study is being conducted as the next phase of this project. The visual study results will help establish thresholds for visually perceptible and acceptable hue differences in spot color tints. The threshold from that study will be used to formulate statistical hypothesis and conduct hypothesis testing. If the observers do detect a visual difference between the print, PantoneLIVE and the hue corrected versions, it would be worth evaluating which version do they feel appears more natural when seen with the solid. It would also be worth repeating this study with high chromaticity colors in other hue regions to see if the relationship is replicated across the different regions. Additionally, a chromatic adaptation transform could also be tested with these hue shift metrics to check if the accuracy of these metrics improves.

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CH. 3 COLOR ACCURACY IN BIODEGRADABLE PAPERBOARD PACKAGING WITH ECO-FRIENDLY INKS

Anissa Mollett

Introduction

With growing concern for the environment and the emergence of eco-friendly alternatives across all industries, there is a need to perform research on more sustainable solutions within the packaging industry. The use of more environmentally friendly substrates and inks should be explored as an alternative to petrochemical-based inks that have detrimental effects on the environment. The definition of a sustainable or environmentally friendly ink may differ between print companies and ink manufacturers. For the purposes of this study, bio-renewable inks are used as the eco-friendly ink set. The USA National Association of Printing Ink Manufacturers (NAPIM) defines a bio-renewable ink as being derived from tree, plant, insect and/or animal materials (Sun Chemical, 2018). Along with being derived from natural materials, bio-renewable inks should not have more than trace levels of heavy metals and reduce volatile organic compounds that are released into the atmosphere (Sun Chemical, 2018). These inks do not have the same negative impacts on the environment as petrochemical-based inks.

In addition to their environmental impact, it is important to consider the impact eco-friendly inks have on color reproduction. Consumer brands place importance on color as a way to build brand awareness and help shoppers recognize their products against competitors. The ability to produce packaging that retains brand color accuracy and desired aesthetic properties, while providing benefits to the environment opens new opportunities for the future of the packaging industry. This study analyzes color accuracy and durability properties of eco-friendly inks compared to petrochemical-based inks printed on biodegradable paperboard.

Two Clemson brand colors were referenced as color standards for the experiment, Clemson Orange, Pantone 1595 C and Calhoun Fields, Pantone 583 C. The eco-friendly ink is hypothesized to be able to obtain a ΔE_{00} (Delta E 2000) color difference of 2.0 or below as this is commonly accepted as the threshold for the human eye's ability to perceive color difference.

On press, adjustments were made to impression, press speed, and anilox roll configurations to achieve the printed color target. A test target and package design press run were completed. Samples were collected from each test run to analyze solid ink density and ΔE_{00} values. Averages were calculated of the measured samples to confirm consistent ink density on the operator and gear sides of the press as well as the average ΔE_{00} values achieved on press.

Objective

The purpose of this study is to answer the following questions: 1) Can brand color accuracy be achieved by obtaining a ΔE_{00} color difference of 2.0 or below using currently available eco-friendly inks and biodegradable substrates? 2) If the eco-friendly inks fail to match, what drawbacks could keep these materials from being widely accepted?

Materials

Inks

Flexographic water-based inks were used to conduct this experiment.

Sun Chemical provided two ink formulations, CHROMAFINE™ that served as the petrochemical-based ink and AquaGreen™ that served as the eco-friendly ink. The Pantone colors along with the L*a*b* values were provided for color matching with a tolerance of ΔE_{00} difference of 2.0 or below. Each of the inks were color matched within tolerance by Sun Chemical prior to the press trials.

The pigments used for both formulations remained constant and the essential difference between the petrochemical-based inks and eco-friendly inks was the ink vehicle. The ink vehicle is an essential component of the ink as it holds the pigment and binds it to the surface of the substrate. The type of vehicle used in an ink affects how the it dries and the overall quality of the ink on the printed surface. Within this report, the CHROMAFINE™ (PMA) formulation contains a petrochemical based ink vehicle and the AquaGreen™ (DPA) formulation contains a bio-based ink vehicle in which the contents are bio-renewable.

Table 1 displays the target L*a*b* values for the two Clemson Brand colors and the anilox roll specifications used for each print trial. The values in parentheses represent the number of anilox rolls with this configuration that were used during the press run.

Table 1

	L*	a*	b*
Clemson Orange Pantone 1595 C	56	47	59
Calhoun Fields Pantone 583 C	76	-16	71
Anilox Roll Specs Press Run #1	800 cpi, 2.0 BCM, 60°(4)		
Anilox Roll Specs Press Run #2	800 cpi, 2.0 BCM, 60°(3)	550 cpi, 3.0 BCM, 60°(1)	

Substrate

WestRock 14 pt. PrintKote coated paperboard was used for both press runs. Paperboard is often manufactured using recycled materials, but certain substrate additives may cause the product to no longer be considered biodegradable or compostable after its initial use. The PrintKote substrate is recyclable and does not contain optical brightening agents (OBAs). A fluorescence test using a Judge QC X-rite Light Booth confirmed there were no OBAs present in the substrate. Optical brighteners contain harmful organic chemicals that have been found to contaminate aquatic bodies as they are not easily degradable by wastewater treatment (Ginebreda et al., 2011). The paperboard also contains elemental chlorine free (ECF) bleached fibers. The ECF bleaching process serves as an environmentally friendly alternative to traditional fiber bleaching. This process substitutes the use of molecular chlorine for chlorine dioxide, reducing water usage and toxic waste (Bajpai, 2018).

Methodology

Dupont DFR 0.067in. photo-polymer plates were exposed on a Dupont Cyrel® Fast exposure unit and imaged using an Esko CDI Spark 2530. The plates were thermally processed on a Cyrel® Fast thermal processor. All plates had a 0.020in. plate relief within the Flexographic Image Reproduction Specifications & Tolerances (FIRST) guidelines accepted by many printers in the industry for flexographic platemaking. The plates were then mounted on plate cylinders with a 15in. repeat using 3M E1315 mounting tape. Two press runs were completed for each type of ink, the first being a test target run and the second being a graphics press run for a paperboard package.

Prior to each press run, the viscosity and pH of the inks was recorded using a #3 Zahn cup and a pH meter. Flexographic inks typically have between an 8.5 and 9.5 pH range. The viscosity and pH measurements are shown in Table 2.

Table 2

	Test Target Run (Press Run #1)		Graphics Run (Press Run #2)	
	Viscosity	pH	Viscosity	pH
CHROMAFINE (PMA) 1595 C	57 s	9.68	52 s	9.93
AquaGreen (DPA) 1595 C	60 s	9.44	65 s	9.33
CHROMAFINE (PMA) 583 C	28 s	9.36	22 s	9.28
AquaGreen (DPA) 583 C	26 s	9.74	25 s	9.61

**s=seconds*

This study was conducted on a Comco Captain Series 10in. narrow-web inline flexographic press with six print stations. Four stations were used for both the test target and graphics run. The graphics run consisted of a design that was converted into a paperboard package. On press, adjustments were made to press speed, impression settings, and anilox roll configurations.

Table 3.1 Average Solid Ink Density
Operator and Gear Side

	583 C Operator	583 C Gear
PMA	1.29	1.29
DPA	1.25	1.25

	1595 C Operator	1595 C Gear
PMA	1.39	1.39
DPA	1.29	1.29

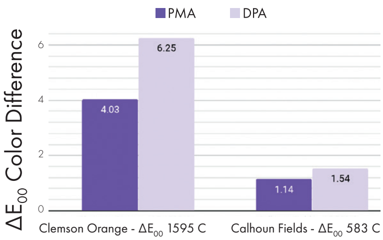
Table 3.2

	L*	a*	b*
Clemson Orange Pantone 1595 C	56	47	59
Calhoun Fields Pantone 583 C	76	-16	71

Table 3.3 Average ΔE_{00} Values
Press Run #2

	ΔE_{00}	Δ L*	Δ a*	Δ b*
PMA Orange 1595 C	4.03	4.21	-1.27	2.33
PMA Green 583 C	1.14	0.58	-0.98	-2.76
DPA Orange 1595 C	6.25	6.37	-2.52	4.36
DPA Green 583 C	1.54	1.08	-1.40	-3.18

Fig. 1 Comparison of the achieved ΔE_{00} values for each ink set from Press Run #1



Test Target Press Run

The initial test target press run was completed using four water-based inks, two Clemson brand colors and two auxiliary colors for the graphic elements. After either of the ink sets, petrochemical based or bio-based, were run on press, the plates, ink chambers, and anilox rolls were cleaned thoroughly to avoid contamination. All four stations contained an 800 cpi, 2.0 BCM anilox roll and the press ran at 110 feet per minute (ft./min.). A marker was placed in the rewind roll, the press speed was increased to 110 ft./min. and additional markers were placed in the rewind roll after each minute for five minutes. Four print samples were pulled after each minute. Solid ink density and ΔE_{00} measurements were taken from 20 samples and the average values for each ink are shown below in Table 3.1 and Table 3.3. The target ΔE_{00} L*a*b* values are shown in Table 3.2.

Graphics Press Run

For the second press run, the same four inks were used with 800 cpi, 2.0 BCM anilox rolls in each station. Once impression was set and all of the graphics were registered, the press speed was increased to 110 ft./min. to remain consistent with the first press run. A sample was pulled and analyzed for ΔE_{00} and solid ink density on both sides of the press. The CHROMAFINE™ (PMA) formulation was run on press first and the ΔE_{00} value recorded for the orange ink was too light in color, indicated by a positive ΔL* value. Adjustments were made to press speed and impression was increased but this did not bring the ΔE_{00} value of the orange within tolerance. The anilox roll in the Clemson Orange station was then changed to a 550 cpi, 3.0 BCM to increase ink film thickness and darken the color. The press speed was increased to 115 ft./min. and the ΔE_{00} of the orange ink fell within the set tolerance for the experiment.

The plates, ink chambers, and anilox rolls in the orange and green ink stations were cleaned and replaced with the AquaGreen™ inks. Due to the ΔE_{00} measurements with the previous orange ink, the 550 cpi, 3.0 BCM anilox roll was used for the eco-friendly ink.

Table 4.1 Average Solid Ink Density
Operator and Gear Side

	583 C Operator	583 C Gear
PMA	1.57	1.57
DPA	1.48	1.48

	1595 C Operator	1595 C Gear
PMA	1.55	1.55
DPA	1.45	1.46

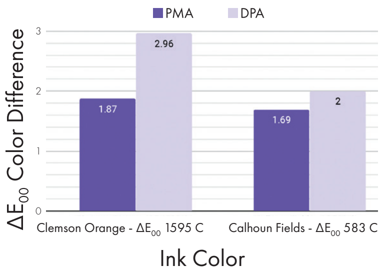
Table 4.2

	L*	a*	b*
Clemson Orange Pantone 1595 C	56	47	59
Calhoun Fields Pantone 583 C	76	-16	71

Table 4.3 Average ΔE_{00} Values
Press Run #2

	ΔE_{00}	Δ L*	Δ a*	Δ b*
PMA Orange 1595 C	1.87	0.15	0.91	5.19
PMA Green 583 C	1.69	-2.08	-1.42	1.41
DPA Orange 1595 C	2.96	1.58	-0.90	5.61
DPA Green 583 C	2.00	-2.26	-2.04	-0.12

Fig. 2 Comparison of the achieved ΔE_{00} values for each ink set from Press Run #2

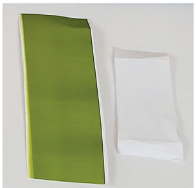


Once impression and registration were set a sample was pulled to measure ΔE_{00} and solid ink density on both sides of the press. The press speed was increased to 115 ft./min. and the ΔE_{00} value for the orange ink was too light in color for this formulation as well. The impression was increased and further adjustments to press speed were done to achieve the lowest ΔE_{00} value possible with the current press conditions. A ΔE_{00} value of 3.0 was the lowest measurement attainable at press speed of 100 ft./min. Ten samples were taken after running the press at this speed for one minute. Solid ink density and ΔE_{00} measurements were taken from 10 samples of each ink set and the average values for each ink are shown in Table 4.1 and Table 4.3. The target ΔE_{00} values are shown in Table 4.2.

Additional Testing

Sutherland Rub Test

Ink drawdowns were completed using a hand proofer with a 500 cpi, 3.0 BCM anilox roll. The five ink samples were used to complete a Sutherland Rub Test. The Sutherland rub test consisted of 30 passes using a two-pound weight.



CHROMAFINE™ (PMA)
Calhoun Fields Pantone 583 C

AquaGreen™ (DPA)
Calhoun Fields Pantone 583 C

CHROMAFINE™ (PMA)
Clemson Orange Pantone 1595C

AquaGreen™ (DPA)
Clemson Orange Pantone 1595C

Differences in the rub resistance of the petrochemical-basedinks compared to the eco-friendly inks were observed. Visually, the petrochemical-based inks had better rub resistance properties than the eco-friendly inks. Scuff marks consistently appeared on the eco-friendly ink samples for each iteration of the test. The images in Figure 3 show the visual differences in rub resistance between the CHROMAFINE™ petrochemical-based inks and the AquaGreen™ eco-friendly inks.

Coefficient of Friction

The coefficient of friction (COF) test records the amount of force required to move an ink sample and keep it moving for a set period of time. Six drawdowns of each ink color were used to complete this test. Each sample was pulled across the flatbed of a FP-2250 Friction/Peel Tester for a distance of six inches. The additives within the ink or any coating that is applied on top of the ink can affect how easily the sample moves and the coefficient of friction value. Generally, waxes and coatings decrease COF values. The average static and kinetic COF values for each ink type are shown in Table 5.

Table 5

	Static COF	Kinetic COF
PMA Orange 1595 C	0.209	0.164
DPA Orange 1595 C	0.217	0.176
PMA Green 583 C	0.175	0.145
DPA Green 583 C	0.189	0.164

Experiment Findings

The results of the press run and the additional ink tests described in this report display the properties of eco-friendly inks (DPA) compared to petrochemical-based inks (PMA). Three of the four inks tested had an average ΔE_{00} measurement of 2.0 or below, compared to the target Clemson brand color. The average ΔE_{00} value for the orange eco-friendly ink was ΔE_{00} of 2.96, which was not within the tolerance of the experiment. Overall, the petrochemical-based inks had a lower average ΔE_{00} measurement than the eco-friendly inks.

Ink drawdowns tested for rub resistance showed that eco-friendly inks did have less rub resistance than the petrochemical-based inks. This may be attributed to the petrochemical-based ink containing a wax or additive to prevent scratching of the ink surface. The PMA ink formulation also recorded a lower average coefficient of friction measurement than the DPA inks suggesting the ink may contain wax additives. An important consideration when using eco-friendly inks is that in some instances they may require an additional coating, such as an aqueous coating, to improve rub resistance.

Considerations for Industry Research

There is an opportunity to expand this research into multiple avenues of the printing industry. This experiment could be expanded by using multiple bio-renewable inks on biodegradable substrates and completing tests to determine if these products are compostable. An ink using a high percentage of bio-renewable materials that are printed on an eco-friendly substrate could be considered compostable (Sun Chemical, 2018). The use of biodegradable films using eco-friendly inks could transform the flexible film industry, reducing plastic waste. As online shopping increases, it is also necessary to research eco-friendly ink alternatives for corrugated packaging. Research on eco-friendly product alternatives serves as an opportunity to educate consumers on the importance of environmentally friendly packaging.

Conclusions

Eco-friendly ink alternatives have the ability be comparable to petrochemical-based inks in regards to color matching using the flexographic printing method. Although the majority of the tested inks were within the ΔE_{00} tolerances, one of the eco-friendly inks was unable to meet the color difference metrics set for the experiment. This could potentially be a drawback for widespread adoption of these products if printers are unable to achieve the same color consistency with eco-friendly inks as with petrochemical-based inks. Further research is needed to discover methods for eliminating these variances in color on press.

The durability of eco-friendly inks is important to consider when deciding if an eco-friendly ink can be used for a printed piece. However, the addition of an ink coating in order to ensure rub resistance in products where eco-friendly inks are used may not be viable depending on the added cost to the printer. Additional research in both of these areas would be necessary before more companies begin to use eco-friendly ink alternatives for consumer products.

Limitations

The ΔE_{00} measurements obtained from this study are specific to the use of a PrintKote paperboard substrate, and two water-based flexographic inks—one eco-friendly ink formulation and one petrochemical-based ink formulation. This experiment had a limited sample size. Additional testing would be needed to observe the effects of using other types of eco-friendly ink alternatives or a different paperboard substrate. Between the two press runs, there were changes in press conditions as classes used the equipment during the semester. This could affect the ink buildup on the anilox rolls, affecting ink laydown, print quality, and ΔE_{00} measurements for the final run.

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CH.4 CLEMSON ORANGE: BRAND COLOR CONSISTENCY

Dovie Jeffcoat

Abstract

This project examines just how well Clemson Orange's color consistency is maintained. The project consisted of testing various samples of flexographically printed 'Clemson Orange' materials. A sampling of products ranging in substrates and sources was collected. These samples were read with a spectrophotometer to determine the Delta-E from true Clemson Orange. Once the data was collected, it was examined to determine the possible cause(s) of the color differences and their magnitude. Digital and lithographic samples were also collected to examine variation across printing processes. Finally, a survey was taken to gauge consumer recognition of Clemson Orange. Clemson students and fans were asked to identify the brand color from a lineup of orange swatches.

Introduction

Clemson University's campus is bursting with orange, but is it truly Clemson Orange? As an institution, the university is tremendously proud and protective of its brand, as it should be. This protection is imperative for such iconic symbols as the Tiger Paw, Howard's Rock, and Clemson Orange. It is vital for brand color to remain consistent and recognizable across platforms and locations.

Color can be used to communicate with or elicit emotions from the consumer, as well as create brand equity. In a study to determine the significance of standardization in global advertising, color had a substantial effect on brand equity when combined with the standardization of graphics (Carassi, 2016). Additionally, Jessica Lee Ridgway's research on brand personality found that color has a strong impact on the personality associated with brands (Ridgway, 2011). Therefore, it can be said that color consistency plays a pivotal role in the relationship between a brand and its consumers.

Review

Color may be measured, discussed, and categorized in various ways. It may be considered as the location and intensity of a spectral reflectance spike on the visual spectrum. It may also be measured by the dot percentages of color separations such as Cyan, Magenta, Yellow, and Black. Color is often identified using color matching systems such as a pantone swatch book. These ways of thinking about color are valid and useful in their own ways; however, CIELAB will be used in this project as a device independent method of quantifying color.

CIELAB

CIELAB is a color space designed to quantify and communicate hue, chroma, and lightness using a numerical coordinate system.

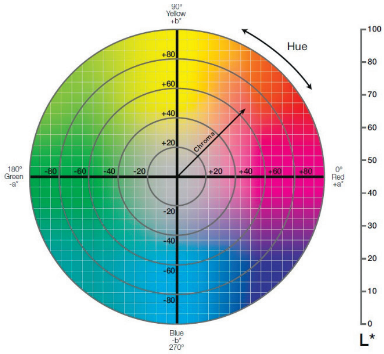

Fig. 1 CIELAB Color Space

Simply put, hue can be thought of as what color an object is (blue, red, yellow, etc.). Hue varies across the wavelengths of the visible spectrum, from violet (400 nanometers) to red (700 nanometers). Chroma, also called saturation, is a measure of a color's intensity. It may also be defined as the purity of a color in relation to neutral gray. For instance, while a color closer to neutral gray looks faded or "dirty", a purer color is more vibrant. Finally, lightness (also called luminance) determines how bright a color is. It is referred to as "achromatic", meaning a lightness value can only identify how light or dark a color is (Sappi, 2013). As shown in Figure 1, the CIELAB color space is a three-dimensional model containing three axes: L* for lightness, and a* and b* for color. The a* axis represents opposing colors red (+a*) and green (-a*), while the b* axis represents opposing colors Yellow (+b*) and blue (-b*).

Color Differences

While CIELAB provides a device independent way to communicate color, it also offers a precise method of measuring color differences. This value is known as Delta E, which pinpoints the exact coordinates of two colors and measures the distance between them. This project will use Delta E 2000, which compensates for the nonuniformity of human color perception using the formula:

$$\Delta E^*_{00}=\sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2+\left(\frac{\Delta C'}{k_C S_C}\right)^2+\left(\frac{\Delta H'}{k_H S_H}\right)^2+R_T\frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

(Schuessler). [1]

Methodology

Print Sample Collection and Measurement

To gain an understanding of the consistency of Clemson Orange in commercially sold products, samples of varying caliper, material, and manufacturer were collected from stores in and around the Clemson area. While the main focus of the project was flexography, digital and lithographic samples were also collected to determine the consistency of Clemson Orange across multiple printing processes. In total, 30 samples were collected, of which 15 (50.0%) were flexo, 7 (23.3%) litho, and 8 (26.7%) digital. Additionally, 18 (60%) of the samples were process color (CMYK) and 12 (40%) were spot color, as shown in Figure 2.

Once collected, the samples were read with a spectrophotometer for L*a*b* data. It is important to note that Clemson University's official color palette contains two pantone options for Clemson Orange. Pantone 165 is typically used for athletics; however, it is so vibrant that it lies outside the process color gamut and cannot be accurately reproduced with CMYK inks. Therefore, the university offers pantone 1595 to be used for CMYK applications. The Delta E between these Pantone colors was measured to be 8.36, which is well above the limit for a noticeable visual difference. This significant difference may contribute to decreased consumer recognition of Clemson Orange.

An X-Rite eXact spectrophotometer was used to measure the Delta E from Pantone 165 and Pantone 1595 for each of the samples. A Pantone+ Solid Coated book was used to reference Clemson Orange. The samples were measured over a standard white backing tile, and the spectrophotometer settings were as follows:

- Iluminant: D50/2°
- Delta E Method: 2000
- Measurement Condition: M1

Survey

An in-person survey was conducted to gauge consumer recognition of Clemson Orange when compared to other orange swatches of varying shades. Participants were asked to identify Clemson Orange from a lineup of four orange swatches taken from a Pantone Coated book (see Figure 3). Pantone 165 was chosen to represent Clemson Orange because it has been the school's designated color for longer than Pantone 1595. Although it would have allowed for a larger sample

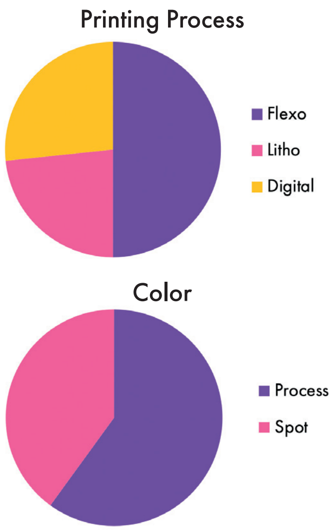

Fig. 2 Processes for Clemson Orange

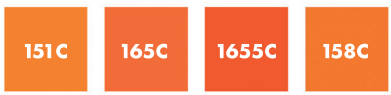

Fig. 3 Survey Pantone Swatches

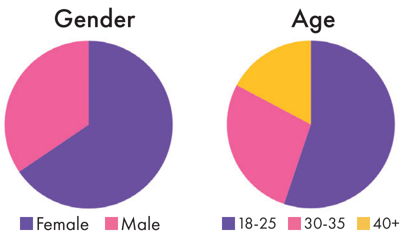

Fig. 4 Participant Demographics

size, an online survey was not used because color may appear differently from screen to screen due to calibration differences.

As seen in Figure 4, the survey consisted of 29 participants, 19 of which identified as female, and 10 identified as male. Additionally, 16 of the participants were between the ages of 18 and 25, 8 were between 30 and 35 years of age, and 5 were 40 years or older.

Results and Discussion

Printed Samples

After collecting the spectral data, the total average Delta E of all samples was found to be 7.21 ΔE from Pantone 165 and 5.82 ΔE from Pantone 1595. As previously stated, Pantone 165 is acceptable for spot color applications, whereas Pantone 1595 is better suited for process color. Therefore, the data can be further analyzed by assuming the spot color samples were matched to 165, and the CMYK samples were matched to 1595. Subsequently, the average ΔE of all spot samples from Pantone 165 was found to be 4.67 with a maximum of 7.37 ΔE. The average of all process samples from Pantone 1595 was 4.92 ΔE with a maximum of 11.41. The data is broken down further by printing process in Figure 5.

Generally, the smallest perceptible color difference to the human eye is said to be 1.0 ΔE. Acceptable tolerances for printing are often set between 2.0 and 3.0 ΔE. However, higher tolerances may be allowed depending on the customer and process (Huda, 2017). As seen in Figure 5, flexo had the lowest ΔE's and digital had the highest. Additionally, for flexo and litho, the process color samples had

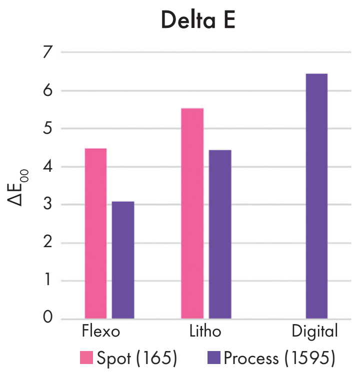

Fig. 5 ΔE by Printing Process

lower ΔE's than the spot color samples. This may be due to how bright and vibrant Pantone 165 is; it might be more easily contaminated and darken on-press. The data seems to support this theory. When looking at the L*a*b* data for the spot ΔE, the averaged values were all negative: L* -5.40, a* -5.18, b* -8.32. This shows a general decrease in lightness and saturation. Alternatively, the spot sample ΔE's could be higher because process color must be tightly controlled, whereas spot inks are simply poured into the press and printed as solids. This may lead to a lack of measurement and control for spot inks due to the assumption that they are already within tolerance.

Survey

After completing an in-person survey, the results showed that 45% of participants correctly selected Pantone 165 as true Clemson Orange (see Figure 6). Furthermore, 34% of participants chose Pantone 158, and 21% of participants chose Pantone 1655, while nobody chose Pantone 151. This is likely because Pantone 151 had the largest ΔE from Pantone 165 (7.51), and therefore the most visually obvious color difference from Clemson Orange.

Of the participants who could not correctly identify Clemson Orange, the majority chose Pantone 158. This may be because 158 had the smallest ΔE from Pantone 165 (4.26). Additionally, Pantone 158 is visually darker and less saturated than 165. As previously discussed, Pantone 165 may tend to darken and desaturate on-press, which could be why participants chose 158. However, Pantone 1595 (Clemson Orange's alternate brand color) is also darker and less vibrant than Pantone 165. Without further analysis, it is impossible to determine which of these factors was causing disruption of consumer recognition for Clemson Orange.

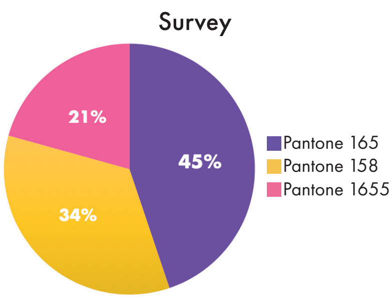

Fig. 6 Consumer Recognition of Clemson Orange

Conclusion

Regarding commercially sold printed products containing Clemson Orange, the data showed that the flexographic samples had the lowest ΔE's when compared to offset lithographic and digital samples. Furthermore, samples produced using spot colors tended to have higher ΔE's across all printing processes. This may be due to Pantone 165's predisposition to darken and desaturate on-press. Additional research is required to confirm this theory.

A survey to gauge consumer recognition of Clemson Orange showed that less than half of Clemson students and fans could identify Clemson Orange from the swatch lineup. Due to several factors, further analysis is required to determine a single cause for the misidentification.

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CH. 5 A STUDY OF PROCESS CONTROL IN EXPANDED GAMUT PRINTING

Teresa Clancy

Introduction

In recent years, an upward trend in the variety of jobs and number of short-run jobs has impacted the graphics industry in many ways. The need for efficiently producing short-run jobs has produced many solutions from enhancements in automation to color management. One method of enhancing efficiency is utilizing expanded gamut technologies.

Brand colors, which are often featured on printed products, have been historically printed with spot colors as opposed to a typical four-color build. Many jobs are printed with CMYK, plus one or two spot colors depending on the job. By adding additional process colors beyond CMYK, the gamut of a press can be expanded to more accurately reproduce brand colors. Depending on one's tolerance for color shift, expanded gamut methods can reduce or even eliminate the need for spot colors. Eliminating spot colors via ECG can lead to a reduction in downtime on press, makeready time, and inventory (Furr, 2015).

Achieving the benefits of ECG does involve some risk. A company may have to overhaul their entire workflow to gain the full advantages the method offers. The shift from a four-color process to a seven-color process requires changes in almost every step of a job's workflow from pre-press to production.

Beyond the implications of application, few standards exist for expanded gamut printing beyond CMYK-only expanded print conditions such as Idealliance's XCMYK and ICC's CRPC-7. For individual ink channels, use of the ISO 20654 standard is on the rise. This standard serves to calibrate and predict spot color tonality using colorimetric tone value, similar to the G7 approach (Ellis 2017). However, standards specific to the ECG production have yet to be published.

By increasing the number of ink stations creating builds, concerns regarding the importance of process control often arise. While builds are still typically made of no more than three inks, the additional stations require a watchful eye on the process: "printers utilizing this technology must have in place superb process documentation and control systems to be successful" (FIRST 6.0). While some research has shown less color shift in seven-color builds compared to four-color builds (Furr, 2015), the extent to which process variation effects ECG color shifts has not been fully analyzed.

A spot's color depends primarily on the ink composition and the substrate reflectance it is filtering. Hence, assuming a white substrate, most color shifts of spot colors occur along the L axis. ECG builds, on the other hand, are often made up of up to three colors. Hence, there is more potential for color shift in the direction of multiple axes compared to that of a typical spot color print.

Objective

This study was designed to observe color shifts in ECG-built swatches and determine the correlation between process control and color variation in ECG color reproduction.

Materials

Plates were made using MacDermid's ITP 60 plate material. Laser imaging was done by the Esko CDI Crystal

and exposure was done using the Esko XPS Crystal. Plates were processed using the Mekrom Evo3 Solvent Plate Processor. The plate was mounted using the Camis Irismal S600 Sleeve Mounter and 3M™ Cushion-Mount™ E1320 mounting tape. Anilox rolls for black, yellow, and magenta were 1200 cpi with 1.8 bcm. The anilox roll for orange had 1200 cpi and 2.2bcm. Substrate used was mactac 60# semi-gloss adhesive paper stock. UVH inks were used.

Methodology

Part I: Building the Target

The target was built to include single-color control patches and patches made up of three-color builds of magenta, yellow, black, or orange. There was a color bar on each side of the web. Nineteen control patches were included on each side of the web, and the remaining patches were builds. The control patches included solid patches for each color and 12 single-color tint patches at 66%, 33%, and 10%. The control patches also included two-color overprints MY, OY, and OM. On the 18-inch repeat, an inch clearance was included on the top and bottom of the target, allowing 81 patches to fit on each side. Hence, there were 162 patches total, including 124 patches of 3-color builds. These builds were combinations of 5%, 33%, 66%, and 100% tints of each included color. Some unlikely builds were eliminated from the target, such as builds of three 100% colors, builds featuring 100% K, and some combinations of 100%, 100%, and 5%. In pre-press the print sequence was set to KYOM, an order recommended for the largest gamut increase (O'Hara, Congdon, Gasque, 2016). Techkon's SpectroVision inline spectrophotometer measurement system was used to collect data during the press run. The SpectroVision uses ChromaQA software to load the artwork, detect the graphics, and collect data. After creating the color bars, ChromaQA was manipulated to measure the designed target.

Part II: Press Run

The press run was performed on the OMET VaryFlex 530 Press. The press was run at 100fpm, which yielded about 67 repeats per minute. After completing makeready operations and achieving consistency on press, the status of the press at that time served as the baseline against which subsequent measurements would be compared. Impression was increased and returned to baseline on each plate in the print order, KYOM.

When controlling impression, the amount of impression increase was recorded and the dependent variable, TVI and its resulting impact on color data, was recorded via the SpectroVision. The impression was increased in two intervals, held at each interval for approximately three minutes and then returned to baseline state.

Data

To observe the impact that process variation has on a color built using the ECG process, patches built of KYOM were measured during each induced variation. Hence, the impact of each variation could be measured in each patch. Because spot colors are made of one ink, while ECG builds of such spot colors are created with multiple inks, the expectation was that the variation would create a larger color shift in these patches than it would in a typical spot color.

Build % vs Color Variation

The charts in Figure 1 show the ΔE_{ab} of each patch as a function of the patch's dot percentage of each ink color. This represents the potential correlation between a single ink station's variation and a build's color. These graphs show the ΔE_{ab} measurement of each patch throughout the entire press run, including the intervals of increased impression. The black chart has fewer data points, as many builds featuring black were eliminated, as stated previously. Aside from yellow, each graph has a slightly positive skew. This suggests that the higher the percentage of these colors is present, the more stable the built color is.

Color Variation

Table 1 displays the ΔE_{ab} data, divided by condition. Total ΔE_{ab} represents the average ΔE_{ab} for each measurement of each patch. The baseline column limits the ΔE_{ab} data to just baseline measurements. The black column limits the ΔE_{ab} data to only measurements within the condition of increased black impression. The yellow, orange, and magenta columns are divided in that same fashion.

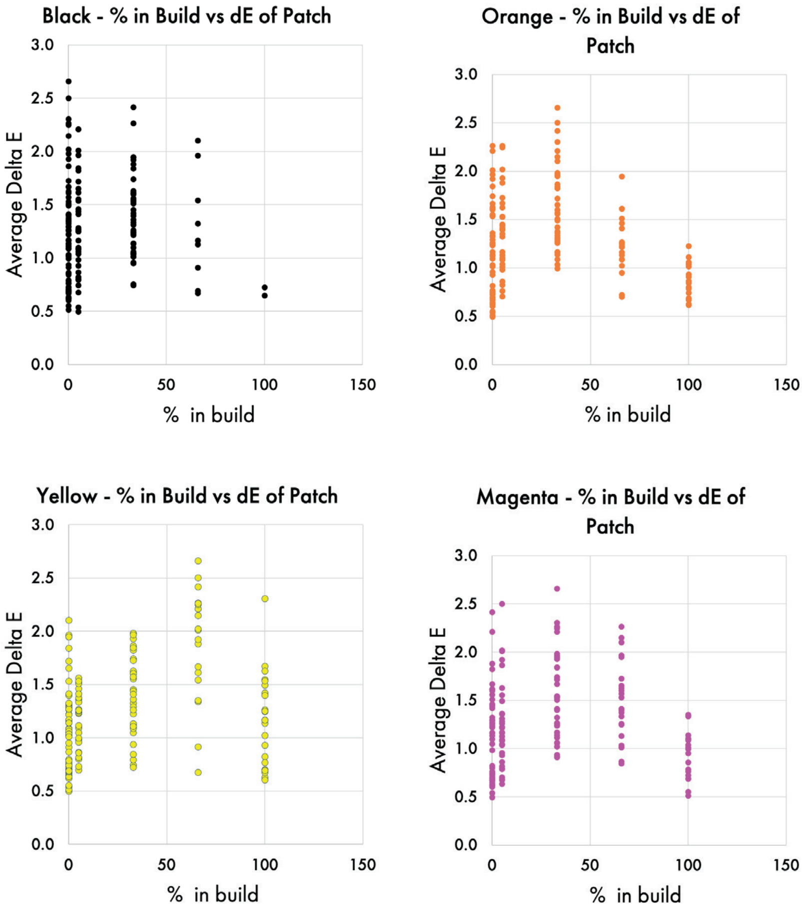


Figure 2. Average ΔEab of Patch

	All	Baseline	K Increase	Y Increase	O Increase	M Increase
Avg ΔE_{ab}	1.395	1.470	1.382	1.570	1.181	1.402
Max Avg ΔE_{ab}	2.660	3.294	2.695	4.747	2.681	2.903
Min Avg ΔE_{ab}	0.674	0.515	0.442	0.446	0.403	0.430
Range of Avg ΔE_{ab}	2.085	2.879	2.353	4.401	2.378	2.573

Table 1. Comparisons of ΔE_{ab} Averages by Impression Increase Interval

By comparing the total ΔE_{ab} data to that of baseline ΔE_{ab}, it appears that the impression conditions had no significantly negative impact on the color variation. In fact, the total ΔE_{ab} appears to have a stronger process control compared to the baseline. However, looking at the ΔE_{ab} data of each impression condition signifies that this is mainly due to the data within the condition of orange impression increase. Still, this data may signify that the ECG method can stay within an acceptable tolerance, even with process variation.

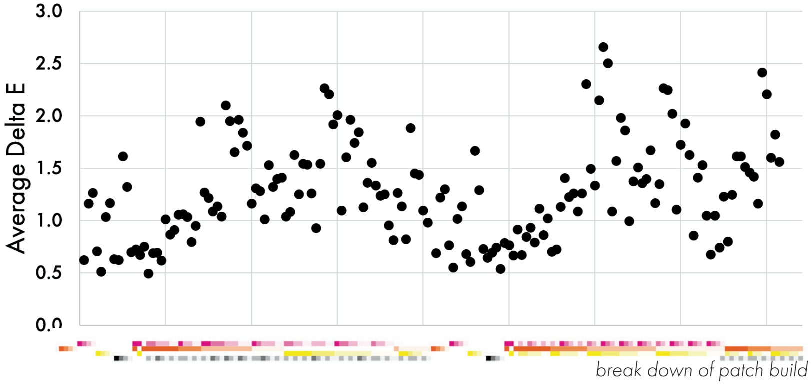
Patch Number x ΔE_{ab}

Figure 2 provides a visual display of the color builds under the x axis. The ΔE_{ab} of each patch is documented on the y-axis. This graph shows that less color shift occurs at the solid control patches. The ΔE_{ab} within these areas is not only lower, but fall within a more condensed area, meaning they have a smaller range. This suggests that the single-color patches are more stable than the three-color builds. Though not a direct comparison between a spot and an ECG build, this result could support the use of spot colors for jobs that require staying within strict tolerances.

Conclusion

This data suggests that ECG colors may be more resilient to process variation than originally thought. Despite significant increase to impression, most ΔE_{ab} measurements did not fall far from the industry standard of 2.0.

Figure 2. Average ΔE_{ab} of Patch



Considerations for Further Research

The data collected in this study did not align with expectations. While this study analyzed certain aspects of process variation on press, there are many other aspects that can impact a run beyond impression. Further, while this examined the stability of ECG builds with process control variation, the builds were not tested directly against spot colors. If this research continues, it would be beneficial to compare spot colors and ECG reproductions side by side, on the same press run. While the study may be limited in terms of patch quantity, it would be beneficial to compare the stability of the colors directly.

Acknowledgments

This paper was adapted from a group project at the undergraduate Graphic Communications program at Clemson University. Group members included Elizabeth Wassynger, Kailey Arnold, Mkyya Johnson, and Anthony Fattibene. Special thanks to Kenny Tucker at The Sonoco Institute of Packaging Design and Graphics for his help with our press runs and data collection. Thank you to John Seymour for helping us organize and analyze the color data. Also, thank you to Steve Rankin for introducing us to Techkon's SpectroVision system and assisting us with the ChromaQA software.

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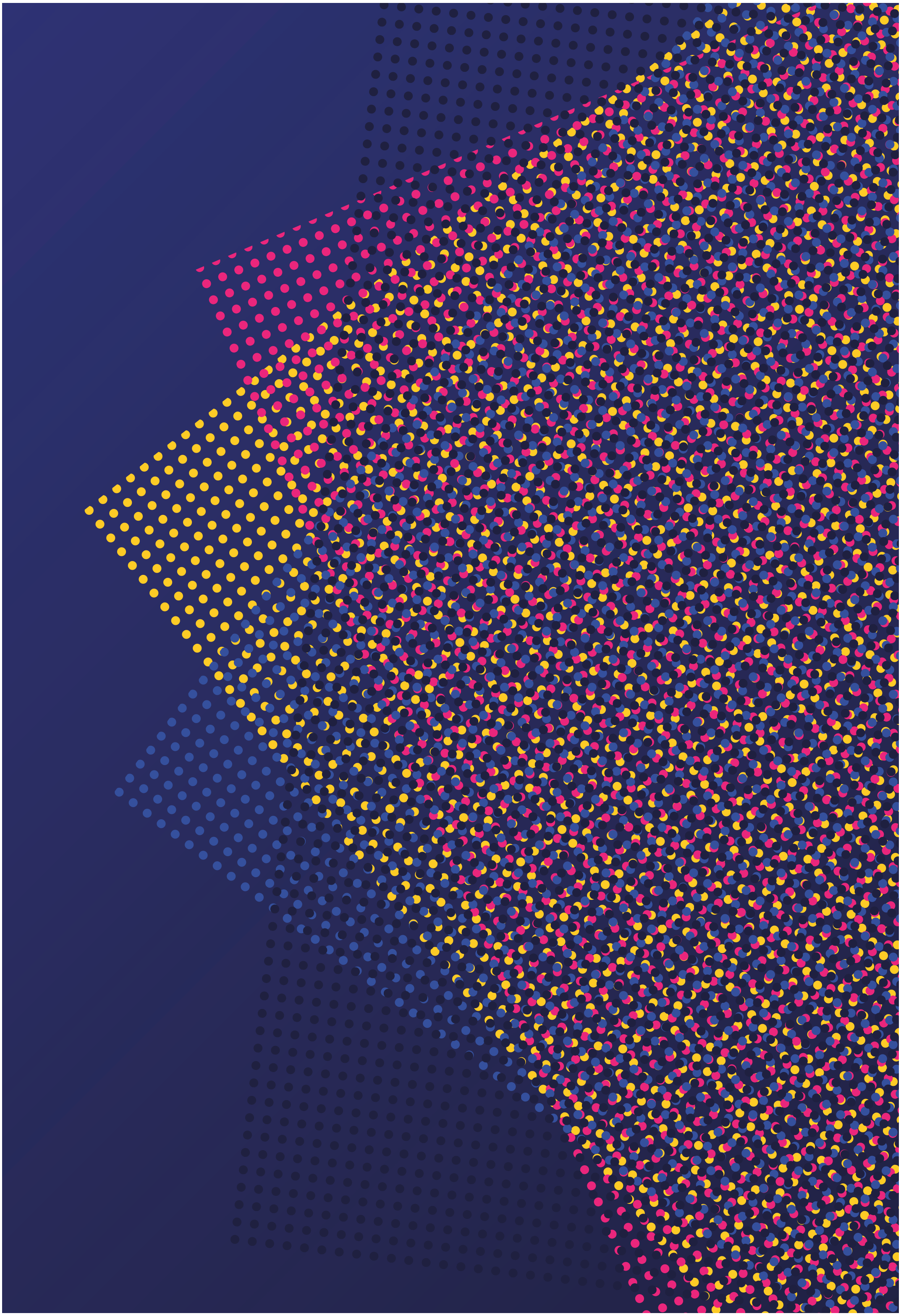

LIAM O'HARA

TAGA Advisor

Dr. Liam O'Hara is an Associate Professor with the Department of Graphic Communications at Clemson University. He teaches the program's notorious research-based class: GC4440 - Current Developments and Trends in Graphic Communications and serves as Advisor to the TAGA student chapter, where he is revered by his students. He is a font of typographical wisdom. His grays are always balanced. Dots worship him. At press trials, he is found to be not guilty. Presses calibrate themselves to his standard. If he were to expand his gamut, it would encompass all of space and time. His colors have no ΔE. He is The Most Interesting Man in Graphics.

TERESA CLANCY

President

My name is Teresa and I am a senior majoring in Graphic Communications and American Sign Language with a minor in Education. I'm originally from the suburbs of New York and came to Clemson unsure of what I wanted to do. I discovered the Graphic Communications program and loved the combination of visual design and technical skills the major offers. This is my third semester in TAGA. I plan to graduate in May of this year and find a job related to print production where I can use my technical skills in the Atlanta, GA area. A fun fact about me is that I have a twin and the two of us went to circus camp one summer.

LAUREN ROBINSON

Vice President

My name is Lauren Robinson and I am a Senior in Graphic Communications at Clemson University. This is my second year as Vice President at Clemson TAGA. I have been taking graphics classes since I was a Sophomore in High School and I truly love every bit of it. I knew Clemson was the best choice for me due to the extensive program and all it has to offer. As of right now I am taking an interest in flexographic printing for a future career. I am extremely grateful to have been able to be a part of TAGA this year. The experiences and opportunities it has offered me have been wonderful.

KYYA JOHNSON

Materials Coordinator – Fall '19

I am a senior at Clemson University, majoring in Graphic Communications with a minor in packaging science. After changing majors from Bio-engineering to Graphic Communications, I discovered a passion for exploring the optimal substrates for packaging and printing processes. I am passionate about business, the fine arts and the technical aspects of Graphic Communications. I've enjoyed further exploring substrates through the creation of the journal in TAGA last year, as well as via previous internships. This year, I am excited to continue doing so as the TAGA Production/ Materials Lead!

BETHANY WHEELER

Production Manager

Hi! I'm Bethany Wheeler. I'm a Senior Graphic Communication Student. I grew up in Snellville, GA, where I attended Gwinnett Technical College for an Associate's in Web Development before transferring to Clemson in 2017. Since starting at Clemson, I have enjoyed being an active member and serving as the treasurer of Gamma Epsilon Tau, the Graphic Communication honorary service organization, and working as a teaching assistant for GC3460 - Inks and Substrates. I also love to travel, so some of my favorite Clemson memories happened while I was studying abroad for the business in pairs program and while attending various industry conferences like AdobeMAX and Color20. I have been having a blast being a part of the Clemson TAGA chapter this year!

TREY BOWE

Creative Director

Hello, my name is Trey Bowe and I'm a sophomore Graphic Communications major. I'm originally from Muncie, IN, but have moved around the country a lot before settling in Fort Mill, SC. This is my second year with TAGA and I was pleased to be able to continue my position as the Creative Director and Social Media Student Ambassador from last year. I joined the Clemson University chapter last year and had the privilege of attending the TAGA 2019 Annual Technical Conference where I enjoyed getting to meet industry professionals and see the amazing work done by some of the other student chapters. I am excited to see how our student chapter applies our collective of skills to keep up with the ever-evolving industry in order to create a unique and inspiring journal.

NICOLE CLAMP

Assistant Creative Director

Hi! My name is Nicole Clamp and I am a Senior, Graphic Communications major. I am from Rock Hill South Carolina. I have always loved art and design and really anything creative. In high school, I started my own sticker business on Etsy (yes, this is a shameless plug) called NC Doodles. That allowed me to share my art with many people from different places. While at Clemson I have gotten to be a part of many clubs and organizations. I am part of the running club, The Tiger Newspaper and even the Chocolate Milk club. I have been involved with TAGA for about two years now and love the people and opportunities for growth that it has given me. I hope you have enjoyed the TAGA journal this year!

CLAY WOODFIELD

Director of 3D Printing

My name is Clay Woodfield. I am a Sophomore Graphic Communications Major raised in Charleston, South Carolina. I initially came to Clemson as an Engineering Major before transferring to Graphic Communications. Due to my previous engineering experience, I am more interested in the industrial side of printing. This is my first semester in TAGA, and I have been enjoying the process of prototyping aspects of the final products. Outside of Graphic Communications, I am the club historian for both the Marksmanship Club and the Clemson Action Shooting Team. These are clubs that I am passionate about and want to see succeed.

ERICA TRYOWSKI
Member

My name is Erica Trykowski and I am a senior Graphic Communications major at Clemson University. I have two minors, one in Packaging Science and the other in Brand Communications. I was born in Cleveland, Ohio, but spent most of my childhood in Greenville, SC. I decided to join Clemson University's TAGA because I wanted to gain experience working in a team to create a product from start to finish. I really enjoy both the creative and technical sides of the Graphic Communications world and by joining TAGA, I could participate in both. My passions include photography, videography, and musical theater. In my free time, I love taking and editing photos and videos. In addition, I also have a love for musical theater. Throughout high school, I performed in musical theater and was a dance captain. Since high school, I have choreographed a couple of musicals throughout Upstate South Carolina. I hope you enjoy this book as much as I did working on it.

ELIZABETH WASSYNGER
Member

My name is Elizabeth Wassynger and I am a senior Graphic Communications major with minors in Digital Production Arts and Business Administration. I've really enjoyed my time at Clemson and have found both the creative and the technical side of the major extremely interesting. This is my first semester in TAGA and it has been an awesome experience so far! Taking a project from start to finish and collaborating with my peers has made me excited about working after college. Participating in TAGA has revealed that there is a lot of space to be creative in the technical side of graphics by combining various printing processes into one book. When I am not working on a project, the time I have is spent with other people. I'm thankful to have such a great family and wonderful friends that mean the world to me. Some activities I enjoy are running, playing the piano, and eating Mexican food whenever possible.

MEGAN SMITH

Member

My name is Megan Smith and I am from Anderson, SC. I took a graphic design class in high school, and I knew right away designing is what I wanted to do as a career. Although I lived thirty minutes away from Clemson, I was unsure what school I wanted to attend. Clemson's Graphic Communications program stood out to me because it offered so much more than any graphic design major. I bridged to Clemson through Tri-County Technical School, and I am now in my second year at Clemson as well as my second year in TAGA. I had a great time last year creating a one of a kind journal with my classmates. I enjoy the challenge of creating a cohesive product from scratch and seeing ideas evolve throughout the semester and go into production. Like most of the classes in our program, TAGA has allowed me to learn many new skills that I hope to take with me into the workforce.

JAMES WEAVER

E-Publication

I am a senior Graphic Communications major from Easley South Carolina. I initially started taking GC classes in high school at the Pickens County Career Center. It's my second year with TAGA, where I am a student ambassador and the head of digital development for the Clemson chapter. I have a love for illustration, graphic design, front end web development, and UX/UI design and hope to one day make a career out of them. TAGA has been a fantastic way for me to gain a great deal more print industry knowledge and make some great connections along the way. When he's not in school, he enjoys making music, fishing, good beer, and playing games with friends.

KASIE NUGENT

Member

My name is Kasie Nugent and I am a sophomore Graphic Communications major with a minor in packaging science at Clemson University. Before coming to Clemson, I interned at different packaging companies, where I was able to learn more about the industry and get hands on experience. This is my first year in TAGA and I have already learned so much about designing and different printing processes. Being a part of this organization has given me many opportunities to explore my major in the real world and has deepened my passion for Graphic Communications. I am very thankful to be able to go to Clemson and have the privilege of working with all the technology that we have. When I have free time, I love to draw, paint, and create new things. Once I graduate, I hope to work designing packaging and displays for different products. I am so excited for everyone to see our book and all the time and hard work it took to create it!

AMANDA PARKER

Member

My name is Amanda Parker and I'm a senior Graphic Communications student with a Packaging Science minor hoping to graduate in the fall of 2020. This fall is my first, and likely only, semester that I'll get a chance to participate in TAGA. I'm excited to work with a team and utilize the different printing and finishing techniques that we have used in classes over the years. I also look forward to applying my packaging knowledge to the project. A little more about me - I'm from the Lowcountry of South Carolina. A former Packaging Science major, I have always been interested in packaging and structural design. I hope to go into a field related where I can merge my packaging and print knowledge. I will not be able to see the final product as I will be interning out-of-state in the spring of 2020, but I am definitely looking forward to the updates and pictures as my classmates bring our ideas and designs to life.

ABBIE SKEEN
Member

Hello, my name is Abbie Skeen. I am from Florence, South Carolina and this is my first year at Clemson and with TAGA. Growing up I always had an interest in digital art and photography. Before coming to Clemson I worked with my local newspaper covering high school and pre-professional sports. This job really showed me that I'd like to work in media and promotional content. I also worked on the yearbook staff which helped me discover how much I love being able to see the final product of hard work. Learning about the Graphic Communications major opened my eyes to the career options that I can pursue. At Clemson I've been involved in the Clemson Waterski Team, Gamma Epsilon Tau, and TAGA this year. Coming into the Graphic Communications major I hope to work with a business or athletics department's social media team to help promote their business or sports team in a positive manner that will raise engagement and boost their social media presence.

KATHRYN TAYLOR
Member

My name is Kathryn Taylor, and I am a junior Graphic Communications major and Voice minor at Clemson. I am originally from Goose Creek, South Carolina, down near the coast. When I applied to the program, I originally thought that I wanted to go into graphic design. However, over the past two and a half years, I have learned so much more about the graphics industry than I expected. I have loved the hands-on experience that the program gives us, through labs as well as the internships we get to participate in. This is my first semester in TAGA, and I am excited for all of the design and research that will go into our journal. Something that I have enjoyed about TAGA so far is the blend between the creative and technical sides of the graphics field. I am hoping that the work I will get to do throughout my time in TAGA will help me get a feel for what I would like to do after graduation.

ALEX ODOM

Member

My name is Alex and I am a senior in the Graphic Communications program. Upon graduating, I plan to apply to graduate programs for 2D/3D animation. I see animation as the best medium in the current technological climate to reach future generations. I aspire to be an animator as a means of self-fulfillment with a skill I have and will continue to work on for many years and to ignite emotional impact within the people who view my work. I am a self-cultivated artist and am learning in my spare time both frame-by-frame animation and Python programming language. I have a meticulous eye and a compulsion for precision. I am an avid reader and love learning for my future career prospects as well as for personal enrichment. I hope to hone in on these skills as I continue to create a portfolio for graduate school.

KELSEY KIRKLAND

Member

Hello, my name is Kelsey Kirkland. I am from Charleston, South Carolina and I am currently a sophomore at Clemson University. I am graphic communications major, but am still unsure about the specific career I would like in the future. I took graphic design classes in high school which led to my interest in this study. It is my first semester taking the TAGA class and I am excited to be a part of a group. It has already shown me that as a graphic communications student that we still work together as a team to collaborate and create an original product. Although, I am still in the beginning classes of this major, TAGA is exposing me to different career choices in this field. As our class progresses I believe that I will enjoy printing the product the most and look forward to working with my group.

CORBETT MOORE

Member

My name is Corbett Moore and I am a junior. I have already completed my first internship which was heavy in all areas except actually printing. With my second internship approaching, I chose TAGA as a way to apply the print-knowledge from each of my courses while working on a long-term project. I enjoy both the creative and practical sides of graphics and have experience in photography, ad generation, writing, interviewing, and running social media. I also love small projects and have done design work for multiple on campus student organizations. In addition to academics, I enjoy being outdoors whether that's being on the water, going on a hike, or going to a football game. I also love to kickbox and am a Delta Zeta. Long term, my ideal career is one where I can work closely with clients to build and maintain their brands through design work, social media, and more.

JULIA MOORE

E-Publication

Hi! My name is Julia Moore and I am a sophomore from Greenville, South Carolina. I have always had a love for the creative side of things, so after touring Godfrey, I knew that Graphic Communications would be a great fit for me. I love learning how to be able to take point "A" all the way to the very end, and everything in between. I enjoy the design side, but I really like the technical side of things too. This is my first semester in TAGA, and I look forward to learning more about how to combine the design side with the technical side. I know TAGA will not only be a wonderful learning opportunity, but a way to put our creative minds to work. I know that this class will be one of the more helpful classes that I take here at Clemson, as learning from peers is one of the most efficient ways to learn things, especially in graphics.

GARRETT POWELL
Member

My name is Garrett Powell and I am currently a senior majoring in Graphic Communications and minoring in Packaging Science. This is my first semester in TAGA and I find it fun to be able to help design and build a book that will stay with Clemson even after I graduate. Being more interested in the technical side of Graphic Communications is what first intrigued me about taking TAGA and how we could use various printing methods to achieve a final product. When I am not working on school work I like to spend my free time hanging out with my friends or playing video games on my computer that I built. I am very lucky to have this awesome experience of being at Clemson doing something I enjoy and having awesome people around who support me!

COURTNEY CARROLL
Member

Hello, my name is Courtney Carroll and I'm a senior and first time TAGA member. I've used my time at Clemson not only to gain knowledge, but also to grow as a person. I've learned valuable teamwork skills and have increased my emotional intelligence. Whether it was in my GC labs, internships, or on the field with Tiger Band, I gained experience in how to successfully work with people in a way that was efficient and fulfilling. I'm a positive, relationship-oriented person who is constantly striving to learn and grow. My skills include, but are not limited to: Adobe Suite, photography, video editing, photo editing, and I can play a mean saxophone.

DIGITAL CONTENT

Visit our website at

www.clemsongc.com/taga

THANK YOU!

We would like to thank everyone who helped us on the production of this journal. We could not have done it without you!

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PRODUCTION NOTES

SOFTWARE

MACHINERY

HP Indigo 5000

Konica Minolta AccurioPress C3080

AreoCut Prime

Fast Bind Elite XT

Polar 78

Protopic III-540

Mimaki 3DUJ-553

Esko Kongsberg C Edge

Cover

Paper Specs:	WestRock Tango Digital 188 lb Cover
Printer:	HP Indigo 5000
Finishing:	Soft Touch Lamination Protopic III-540
	Cut and creased on the AreoCut Prime

Body

Paper Specs:	Verso Blazer Digital Satin 80 lb Text
Printer:	Konica Minolta AccurioPress C3080
Finishing:	Trimmed on the Polar 78

Binding

Finishing:	Perfect binding application Fast Bind Elite XT
	Trimmed on the Polar 78

Slip Case

Paper Specs:	Neenah Vellum Industrial Black Folding Board 18pt
Finishing:	Esko Kongsberg C Edge

Loupes

Printer:	Mimaki 3DUJ-553 Acuity Select
Finishing:	Esko Kongsberg C Edge

Design

Typefaces:	Futura PT, Paratype. Designed by Isabella Chaeva, Paul Renner, Vladimir Andrich, and Vladimir Yefimov. Earth Orbiter, Iconian Fonts