Journal of Imaging Science and Technology® 52(6): 060501–060501-9, 2008.

Quality Analysis of Gravure Spot Color Reproduction with an Ink Jet Printer[1]

Yu-Ju Wu▲, Paul D. Fleming III▲ and Alexandra Pekarovicova
Center for Ink and Printability, Department of Paper Engineering, Chemical Engineering, and Imaging, Western Michigan University, Kalamazoo, Michigan 49008-5462
E-mail: y5wu@wmich.edu

Abstract. *Spot colors are widely used in commercial, product, or packaging printing to obtain a colorful appearance. With the combination of the right software, inks, and media, an ink jet printer can be treated as a digital proofer for spot color printing, providing significant time and cost savings compared to conventional procedures for jobs approval for printing technologies with master image carrier, such as rotogravure, flexography, or offset lithography. An Epson StylusPro 4000 digital printer combined with commercially available raster imaging processors (RIPs) and its own printer drivers were tested and compared. Custom ICC profiles were generated for each print combination, using the gravure production substrate and a manufacturer recommended proofing paper (Epson premium semimatte photopaper). Certain popular Pantone colors and a set of custom spot colors used in gravure decorative laminates industry was investigated and the quality of spot color reproduction was evaluated in terms of the color difference (ΔE^*_{ab}) in $L^*a^*b^*$ color space. The results show that all tested print combinations have higher ΔE^*_{ab} values in highly saturated spot colors, regardless of which printer control software is used. Digital printers employing extended color sets, such as Pantone Hexachrome might be required to reproduce these highly saturated colors. The results also suggested that usage of third party RIP software results in better spot color reproduction. Users can proof spot colors printing via RIPs, if good color matching is considered crucial.* © *2008 Society for Imaging Science and Technology.*
[DOI: 10.2352/J.ImagingSci.Technol.(2008)52:6(060501)]

INTRODUCTION

Color affects the subconscious and influences people—especially when it comes to business. A colorful printing production can grab customers' attention instantly. Spot color, providing attractive color imaging, is widely used in product[1] and packaging printing.[2]

Recently, the trend in the printing industry includes shorter run lengths and work with fast turnaround times. The use of ink jet digital proofing has grown remarkably, due to its benefits of high speed, wide color gamut, and the ability of producing small quantities of high-quality color products at affordable prices for a device. With its unique properties, ink jet digital proofing provides significant time and cost savings compared to conventional procedures (preparing cylinders and printing proof samples) for potential product verification[3] and matching. Digital proofing with good spot color matching is extremely important for product and package printing, since packaging printers require the creation of economical proofs for spot colors.

The possibility of implementing digital proofing is closely related to the recent developments in color management.[4] To mimic actual properties of, for example, a gravure press, using a different printing process, different inks, materials, and possibly devices at different locations, is quite a complex problem. The key to matching proof to press is how accurately the digital color numbers can be manipulated in comparison to printing set up. With a properly color-managed workflow, where correlations between different printing devices are established via device profiles, and characteristics of materials used are taken into account, the flexibility of digital data processing allows digital proofs to simulate printing presses with an ink jet printer.[3–8]

The main components of the ink jet digital proofing system include the ink jet printer, inks, print media, and printer control software with a color management system. Functionally, there are two kinds of software to control a printer. The first one is the printer driver (ink jet printer manufacturer's software); the other one is third-party raster imaging processor (RIP) software. The application of a RGB or CMYK device will depend on the user's workflow.[4,8,9]

Printer driver software generally drives the printer to print data files in RGB mode. A RGB printer can be controlled by three channels. A user sends a RGB image and the printer driver performs the conversion from RGB to CMYK. PostScript printer drivers actually fall into the second category, since the specification[10] requires the ability to process CMYK data among other color spaces. GutenPrint[11] provides a set of CMYK printer drivers for UNIX-based systems (MacOSX, Linux, etc.) that provide open source PostScript support when combined with Common UNIX Printing System.[11] Third-party RIP software interprets raster and vector data files for a specific postscript printer in either RGB or CMYK mode. During the processing period, digital data have been sent to a RIP and the PostScript page description is interpreted. Those page components, raster, and vector images are then translated into bitmapped data files, so that

▲IS&T Member.
[1]Presented in part at the IS&T/SID Fourteenth Color Imaging Conference, November, 2006, Scottsdale, AZ.

Received Jan. 22, 2007; accepted for publication Sep. 5, 2008; published online Dec. 11, 2008.
1062-3701/2008/52(6)/060501/9/$20.00.

Table I. PANTONE Matching System Colors $L^*a^*b^*$ values.

	PANTONE Color Name	PANTONE L*a*b*		
		L*	a*	b*
	Process Yellow C	89	-4	103
	Process Magenta C	45	78	2
	Process Cyan C	57	-38	-46
	Yellow C	89	-4	112
	Yellow 012 C	87	2	114
	Orange 021 C	63	63	95
	Warm Red C	57	71	53
	Red 032 C	54	74	41
	Rubine Red C	44	78	8
	Rhodamine Red C	52	79	-19
	Purple C	46	68	-48
	Violet C	24	54	-71
	Blue 072 C	19	40	-79
	Reflex Blue C	19	32	-74
	Process Blue C	47	-33	-57
	Green C	60	-78	2
	Black C	18	2	6
	Process Black C	9	0	0

a specific output device can understand and deliver commands to control the actions of the output. By controlling CMYK inks directly, RIP software can provide better control for accurate digital color reproduction.[3,4,9,12]

Color transformation in the color management workflow for the digital proofing process highly depends upon the information in the ICC profiles and the calculations performed by using the color management module (CMM).[13,14] When it comes to an ink jet printer matching a press, the effective color gamut mapping by using profiles to do the conversion work is the key to obtaining good color matching results. Vendors offer CMMs working with different conversion mechanisms. For example, Adobe Photoshop with Adobe CMM engine is widely used by designers and printers. Some RIPs have their own CMMs built into the RIP application. By using diverse CMMs, different color matching results may be obtained.

The overall objective of this investigation is to establish a digital proofing system for product gravure printing based on ICC workflow. In product gravure printing, specific color inks are generally used to meet the requirements of a customer. Therefore, the reproduction of PANTONE Matching System[15] colors, as well as custom spot colors used in the gravure decorative laminates industry, was investigated using an Epson StylusPro digital printer with different printer control software. The device gamut will be defined graphically and numerically. The quality of reproduction is evaluated in terms of the usual ΔE^*_{ab} (Ref. 16) in $L^*a^*b^*$ color space for selected spot colors.

PROCEDURES

Spot Color Test Chart

The PANTONE Matching System has 1114 Pantone colors that are mixed from 14 basic Pantone colors, widely adopting by the graphic arts, architectural, paint, and industrial design industry. In this study, certain specific colors were selected due to their frequency of use in gravure decorative laminates production, based on our discussions with industry partners. A color test chart was first built using 18 colors from the PANTONE Matching System library (Pantone coated). The list of selected colors and original $L^*a^*b^*$ values (obtained from the Photoshop PMS Library) is shown in Table I.

With the exception of the blacks, the colors in the chart are of high saturation. The objective was to select challenging color targets and to evaluate the ability of the digital printer to reproduce them. Thus, two blacks, one very dense (Process Black C) and one dirty (Black C) were chosen because dense blacks are also often difficult to reproduce. It was expected that some of the colors would be out of gamut of the devices, contributing to relatively high ΔE^*_{ab} average values. Other less saturated colors than the ones chosen should be relatively easier to reproduce, i.e., resulting in smaller ΔE^*_{ab} values.

The gravure proofer test charts, Blue B-347, Black-392, Red-314, Red-349, Yellow-355, Yellow-357, and Yellow-385 were also evaluated. These are typical spot colors used in gravure decorative laminates. Each chart consisted of 66

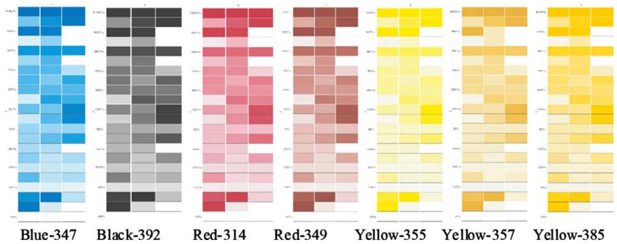

Figure 1. Spot color test charts.

(a) Epson 4000 Printer driver (true color) vs. GMG RIP (black wireframe) (b) Epson 4000 Printer driver (true color) vs. CGS ORIS RIP (black wireframe) (c) CGS ORIS RIP (true color) vs. GMG RIP (black wireframe)

Figure 2. Color gamut comparison on the manufacturer recommended paper for the Epson Stylus Pro 4000 printer. (a) Epson 4000 Printer driver (true color) vs GMG RIP (black wireframe), (b) Epson 4000 Printer driver (true color) vs CGS ORIS RIP (black wireframe), and (c) CGS ORIS RIP (true color) vs GMG RIP (black wireframe).

patches of different gray levels, generating a chart with a variety of shades for the color (as shown in Figure 1). The selected colors were printed on the gravure production substrate by a GMS gravure proofing press. Each specific measured area on the individual chart was measured for $L^*a^*b^*$ values five times to characterize measurement error and the average values was computed as original data. According to these original data, the spot color test charts were generated digitally using Adobe Photoshop CS3.

Color Matching Procedure

An Epson StylusPro™ 4000 ink jet printer with UltraChrome pigmented inks was used, which have been shown to produce good color gamut and durable print with decent lightfastness.[17–20] Three different printer control software-printer driver, CGS ORIS RIP and GMG ColorProof RIP, all under Microsoft Windows XP, were tested and compared. For the Pantone spot color test, manufacturer recommended Epson premium semimatte photopaper was used for testing. For the custom spot color test, the actual gravure production printing substrate, as well as the Epson premium semimatte photopaper were used.

Custom ICC profiles were generated for each print combination. Based on our experience, custom-made profiles are required to describe accurately the characteristics of a device. Generic profiles shipped by the manufacturer do not characterize a given device very well. For the printer driver, a TC 9.18 chart was printed without any color management or color adjustments. Printed charts were then measured with a GretagMacbeth SpectroScanT in reflection mode, using GretagMacbeth Measure Tool 5.0.7 software. The measurement files were used to generate profiles using GretagMacbeth ProfileMaker Pro 5.0.7. The profile settings were as follows: large profile size, neutral gray rendering intent, LOGO classic gamut mapping. The selected spot color test charts were converted from $L^*a^*b^*$ to RGB in Photoshop with absolute colorimetric rendering intent, using the custom profiles. The spot color test charts were then printed via the printer driver. $L^*a^*b^*$ values for each color patch of the printed chart were then measured using the GretagMacbeth SpectroScanT.

For the GMG ColorProof RIP, the ECI2002R CMYK chart was printed without any ink limitation because a specific full gamut color profile is needed to reproduce spot colors. For the CGS ORIS RIP, the calibrated linearization of the printer was used to output the ECI2002R CMYK chart. Printed charts were then measured with the GretagMacbeth SpectroScanT. These measurement files were used as specific color profiles for the RIPs. The specific color profiles were then assigned in relevant functions to perform spot color matching by using their own conversion engine. The selected spot color test charts were printed via the GMG ColorProof RIP, and the CGS ORIS RIP. $L^*a^*b^*$ values for each color patch of the chart were measured using the GretagMacbeth SpectroScanT.

Evaluation of Spot Color Reproduction

The quality of spot color reproduction was evaluated in terms of the ΔE^*_{ab} in $L^*a^*b^*$ color space. Numerous other color difference formulas have been proposed,[21–25] which make "patches" to the original CIE color difference formula[16] without modifying the $L^*a^*b^*$ coordinate system or the gamut volume. Thus, we utilize the original ΔE^*_{ab} because it is consistent with the gamut volume discussed below. In addition, Imai et al.[23] has shown that no formula is superior to the others. Only CIE 2000 (Ref. 22) and Imai et al.[24] allow cross terms in the revised metric, and only Imai et al.[24] allows for a fully general metric, with all possible cross terms. For only CIE94 is there a proposed transformation to a new Euclidian Color Space.[25] The gamuts of the tested devices were the compared visually and numerically using CHROMiX ColorThink 3.0 Pro software.

RESULTS AND DISCUSSION

Gamut Comparison

The gamut comparisons on premium semimatte photopaper for the Epson StylusPro 4000 printer driver, GMG ColorProof RIP, and CGS ORIS RIP were made using ColorThink 3.0 Pro Software, and are shown in Figure 2. The color gamut of the Epson StylusPro 4000 printer driver is similar to the color gamut of the CGS ORIS RIP. Compared to the color gamut of the GMG ColorProof RIP, the Epson StylusPro 4000 printer driver produces a wider color gamut in the yellow region. The color gamut of the GMG ColorProof RIP is similar to that of the CGS ORIS RIP, with exception of the yellow region.

Proofing on the actual production stock more closely predicts "look and feel" of print outcome. For the custom spot color test, the actual gravure production printing substrate was also used for testing. Figure 3 illustrates the color gamut comparisons for the Epson StylusPro 4000 printer driver, GMG ColorProof RIP, and CGS ORIS RIP on the

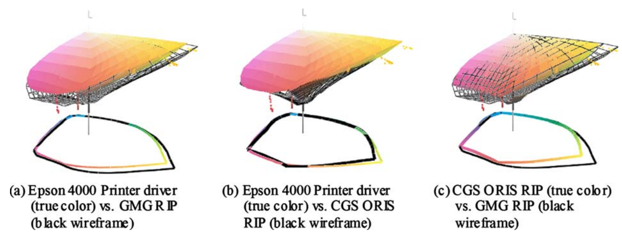

Figure 3. Color gamut comparison on gravure production substrate for the Epson Stylus Pro 4000 printer. The $L^*a^*b^*$ values of the printed gravure production ink on the production gravure paper are plotted for reference. (a) Epson 4000 Printer driver (true color) vs GMG RIP (black wireframe), (b) Epson 4000 Printer driver (true color) vs CGS ORIS RIP (black wireframe), and (c) CGS ORIS RIP (true color) vs GMG RIP (black wireframe).

Table II. Gamut volumes comparison for tested print combinations and substrates.

	Volume		
Printer	Recommended substrate	Gravure substrate	Decrease (%)
Epson 4000 with printer driver	718,000	185, 000	74
Epson 4000 with GMG Colorproof RIP	641,000	228,000	64
Epson 4000 with CGS ORIS RIP	716,000	194,000	73

Table III. ΔE^*_{ab} Comparison of PANTONE Matching System colors for tested print combinations.

PANTONE color	Printer driver	CGS ORIS RIP	GMG ColorProof RIP
Process Yellow C	2	2	4
Process Magenta C	4	2	4
Process Cyan C	1	2	2
Yellow C	9	2	11
Yellow 012 C	13	7	16
Orange 021 C	34	25	29
Warm Red C	14	8	9
Red 032 C	13	8	8
Rubine Red C	3	3	4
Rhodamine Red C	5	4	4
Purple C	15	10	13
Violet C	27	17	18
Blue 072 C	22	16	16
Reflex Blue C	15	7	9
Process Blue C	1	2	1
Green C	6	4	7
Black C	2	4	2
Process Black C	4	3	8
Average	**11**	**7**	**9**

gravure production substrate (with $L^*a^*b^*$ values of original data for reference). As shown in Fig. 3, there are some saturated colors that the GMG ColorProof RIP can achieve that the printer driver and CGS ORIS RIP cannot. The Epson StylusPro 4000 printer driver gamut is larger in the higher L^* value region, while the CGS ORIS RIP gamut is larger in the lower L^* value region. The GMG ColorProof RIP yields a wider gamut in the yellow region. It is important to note that some shadow tints in the spot color test charts are out of color gamut of the printer on this substrate, regardless of how it is controlled.

Another means of quantifying and comparing the size of the gamut is to calculate the gamut volume by numerical integration. The color gamut of a given printing system was evaluated in terms of gamut volume, which can be interpreted as the number of independent colors that can be printed on the designated substrate within a ΔE^* tolerance of $\sqrt{3}$ (i.e., the diagonal of a unit cube). Volume is then expressed per cubic CIELAB units (cCu). Higher volumes indicate the possibility of making more color combinations.[18,20,26] The comparisons of gamut volumes for the tested print combinations and substrates are shown in Table II. Overall, the largest gamut is obtained when the manufacturer recommended substrate is used. The Epson StylusPro 4000 printer driver tends to yield the largest color gamut on the recommended Epson premium semimatte photopaper. The actual production gravure substrate has a significantly smaller color gamut, regardless of which printer control software is used, with gamut volume decreases of about 65%–75% (Table II). Epson ink systems are water based, containing up to 95% water. In order to absorb ink quickly, printing media need to provide a microporous structure for the absorption of vehicle, and large surface area. The ink vehicle should be quickly trapped in the paper structure.

The manufacturer recommended substrate is intended for printing with solvent-based inks and has much smaller pore size (47.4 nm) and its PPS porosity is around 0.85 ml/min, which may result in selective vehicle absorption. The gravure production substrate has a more open structure (with average pore size of 396.9 nm and PPS porosity of 260 ml/min), probably absorbing pigment along with vehicle, which most likely resulted in the smaller color gamut. The printer driver and the CGS RIP perform similarly to one another on both substrates with respect to gamut volume. In contrast, the GMG RIP showed significantly less decrease in gamut on the gravure paper. The cause of this is unclear.

PANTONE Matching System Color $L^*a^*b^*$ Comparison

The comparisons of original and printed $L^*a^*b^*$ values for each Pantone spot color are shown in Table III. This comparison demonstrated that the EPSON StylusPro4000 printer in combination with the CGS ORIS RIP is best suited for the selected spot colors reproduction. The comparison of calculated average ΔE^*_{ab} values for each printer confirmed the good spot color reproducibility for the EPSON StylusPro4000 printer in combination with CGS ORIS RIP (average ΔE^*_{ab} of 7), closely followed by the

Table IV. Summary of ΔE^*_{ab} comparison for different print combinations.

	ΔE^*_{ab} on gravure production printing substrate			ΔE^*_{ab} on manufacturer recommended paper		
Spot colors	Printer driver	ORIS RIP	GMG RIP	Printer driver	ORIS RIP	GMG RIP
Blue-347	5.5,0.4,19.8	2.4,0.1,9.9	1.4,0.1,8.3	1.8,0.4,17.5	1.5,0.4,7.1	0.6,0.1,2.0
Black-392	3.9,0.9,8.3	2.6,0.2,10.6	1.5,0.2,6.9	1.3,0.5,2.4	1.2,0.2,2.3	0.6,0.2,1.7
Red-314	5.9,1.0,23.7	2.3,0.0,9.9	1.5,0.3,7.8	1.6,0.3,3.2	1.7,0.4,3.2	0.9,0.1,2.9
Red-349	3.5,0.4,8.9	1.4,0.2,4.8	1.1,0.1,4.9	1.8,0.8,3.2	1.6,0.3,2.9	1.0,0.1,5.6
Yellow-355	4.4,0.3,18.9	1.1,0.2,2.7	1.4,0.1,5.3	1.9,0.7,5.0	1.6,0.2,3.8	1.6,0.6,2.5
Yellow-357	4.0,0.2,38.4	1.0,0.2,2.1	1.1,0.1,2.2	1.8,0.7,3.2	1.8,0.2,4.7	0.9,0.1,1.4
Yellow-385	8.2,0.2,28.1	4.1,0.0,12.4	4.5,0.2,16.4	4.9,0.9,12.9	3.7,0.2,7.2	3.4,0.4,6.4

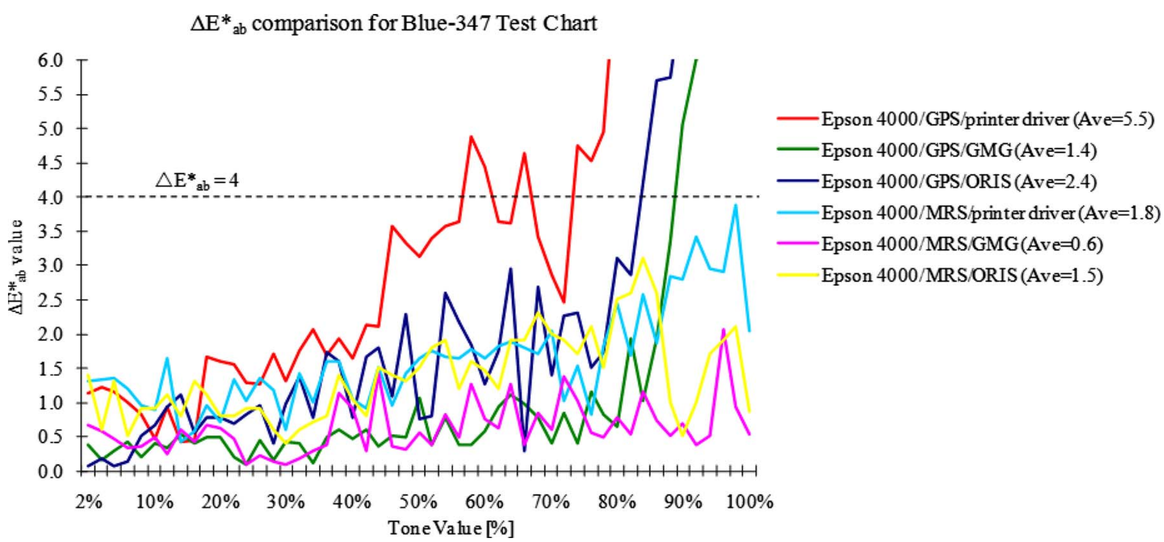

Figure 4. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Blue-347 chart.

EPSON StylusPro4000 printer in combination with the GMG ColorProof RIP (ΔE^*_{ab} of 9) and EPSON StylusPro4000 printer in combination with printer driver (average ΔE^*_{ab} of 11). This is in spite of the fact that the printer driver generated a larger gamut volume than either of the RIPs.

Improved color matching using the two RIPs is at least in part due to the advanced color matching features included with the software. Some highly saturated Pantone spot colors are out of gamut of the devices and cannot be printed on these printer/substrate combinations with satisfactory results, contributing to relatively high ΔE^*_{ab} average values. Other less saturated colors are relatively easier to reproduce.

Custom Spot Color $L^*a^*b^*$ Comparison

The ΔE^*_{ab} values calculated from original and actual printed $L^*a^*b^*$ values for custom spot colors are shown in Table IV. In all cases, absolute colorimetry rendering intent was employed to obtain the best overall absolute color match for each printer/controller/paper combination. The first ΔE^*_{ab} value indicates the average ΔE^*_{ab} value for each spot color chart. The second ΔE^*_{ab} value is the minimum ΔE^*_{ab} value, while the third value shows the maximum ΔE^*_{ab} value among 66 patches for each spot color. Printing on either the actual gravure production substrate or manufacturer recommended paper, both commercially available RIPs provide better color reproduction for the selected spot colors. Except for the Yellow-385 spot color, the average ΔE^*_{ab} values of selected spot colors are all lower than 4.

Figures 4–10 present line charts of ΔE^*_{ab} comparisons of original and printed $L^*a^*b^*$ values for Blue-347, Black-392, Red-314, Red-349, Yellow-355, Yellow-357, and Yellow-385 charts, respectively. The dashed-line represents the reference of 4 ΔE^*_{ab}, where 2–5 ΔE^*_{ab} is generally regarded as barely perceptible color differences in high-quality imaging systems.

As shown in Figs. 4 and 5, the ΔE^*_{ab} values of the gravure production substrate with the Epson StylusPro 4000 and its own printer driver combination (red line) are significantly larger than those of the RIPs. The gravure production substrate tends to have higher ΔE^*_{ab} values for the shadow area. The manufacturer recommended proofing paper,

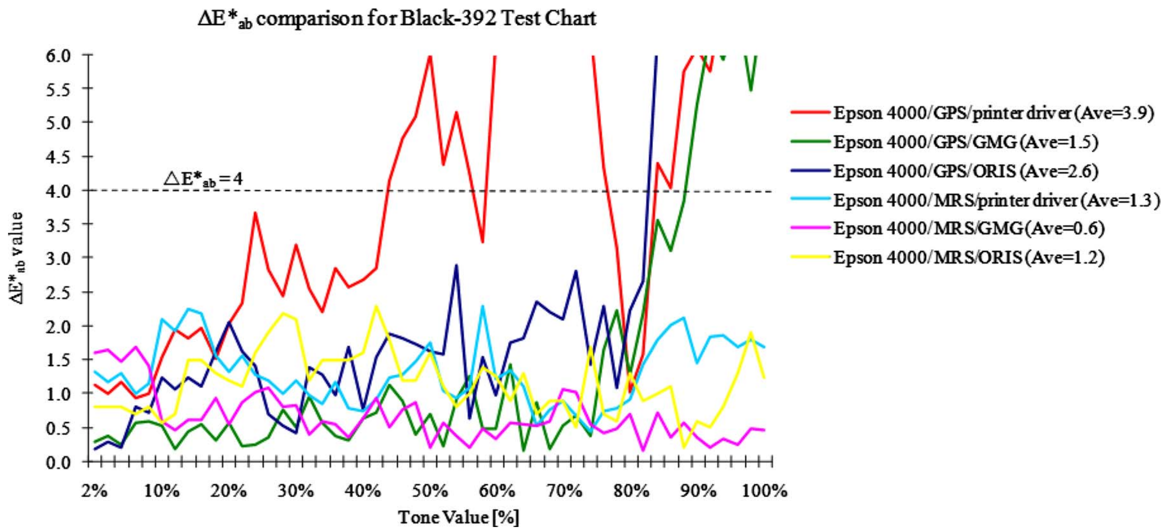

Figure 5. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Black-392 chart.

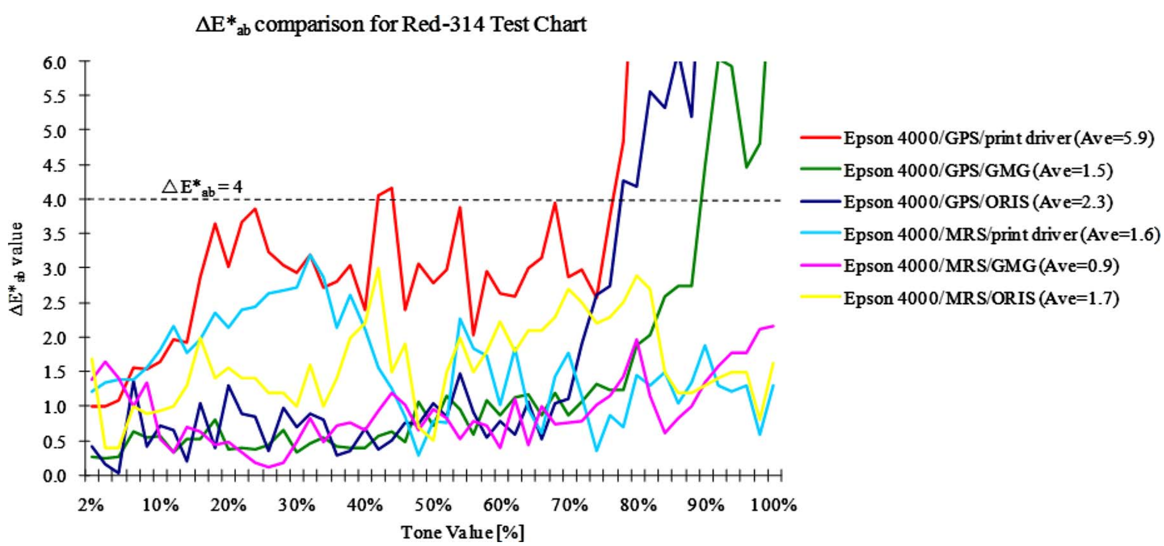

Figure 6. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Red-314 chart.

printed via either printer driver or RIPs, has good reproduction capabilities in the selected spot colors in terms of lower ΔE^*_{ab} values. The manufacturer recommended proofing paper, with a wider color gamut, allows the digital printer to reproduce highly saturated spot colors.

For Red-314 and Red-349 spot colors, as shown in Figs. 6 and 7, the ΔE^*_{ab} values of the gravure production printing substrate with the Epson StylusPro 4000 and its own printer driver combination (red line) are significantly larger than those of the RIPs. The gravure production printing substrate tends to have higher ΔE^*_{ab} values for the shadow area. The ΔE^*_{ab} values of manufacturer recommended proofing paper, conversely, are all lower than four.

Figs. 8 and 9 show that the ΔE^*_{ab} values of the gravure production substrate with the Epson StylusPro 4000 and its own printer driver combination (red line) are significantly larger than those of the RIPs. For the Yellow-355 spot color, the ΔE^*_{ab} values of the gravure production substrate with the Epson StylusPro 4000 and its own printer driver combination increase significantly in shadow areas. Other print combinations have better reproduction capability in terms of lower ΔE^*_{ab} values. For the Yellow-357 spot color, the ΔE^*_{ab} values of tested print combination are all controlled in the range of 0–4, with the exception of the gravure production substrate/Epson StylusPro 4000/printer driver combination. The Yellow-385 spot color, compared to other spot colors, has relatively high ΔE^*_{ab} values. As shown in Fig. 10, the ΔE^*_{ab} values of over four come from the tint greater than 50%.

CONCLUSIONS

The accuracy of proof-press color matching is affected by the printer, software, and substrate involved in the digital proofing processes. There is also a significant dependence of color reproduction on the choice of substrate. This is manifest

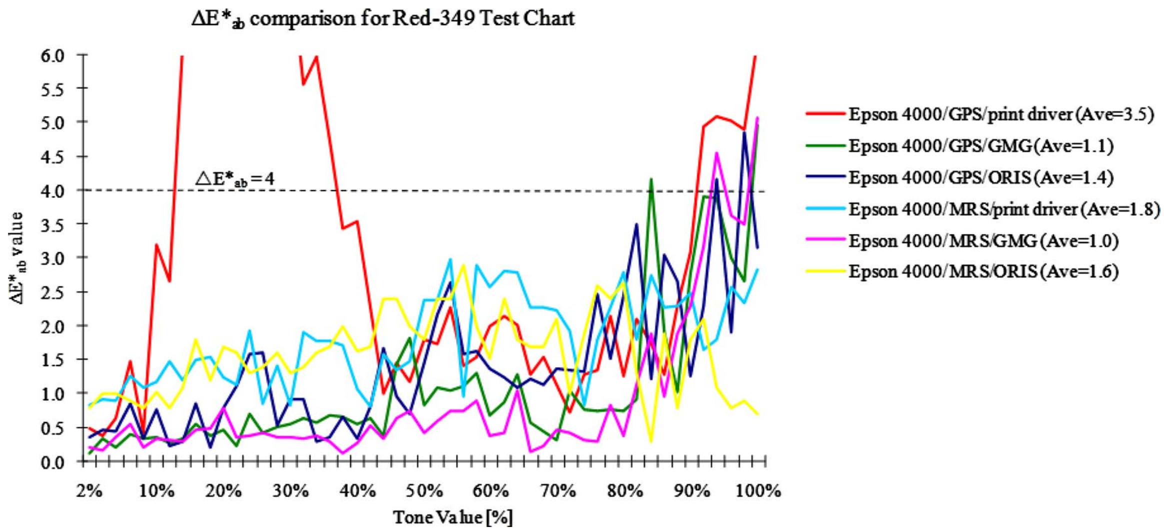

Figure 7. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Red-349 chart.

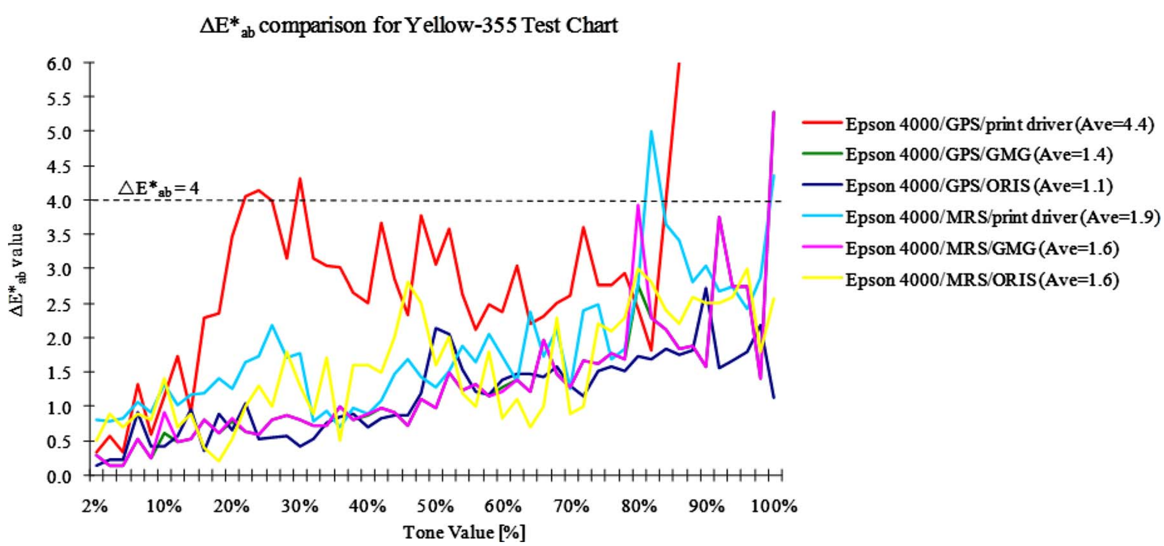

Figure 8. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Yellow-355 chart.

when attempting to proof spot colors on the same substrate as employed on the gravure production press.[27] In this study, the characteristics of the gravure production substrate are quite different from the manufacturer recommended substrate, which has been designed to be printed with a water-based ink. It was found that the gravure production substrate does not work well in the shadow areas with the ink jet digital printer. The Epson ink system is water based, containing up to 95% water. In order to absorb ink quickly, printing media need to provide a microporous structure for the absorption of ink solvents. The manufacturer recommended substrate has a much smaller pore size (47.4 nm) and its PPS porosity is around 0.85 ml/min. The gravure production substrate has a more open structure (with average pore size of 396.9 nm and a PPS porosity of 260 ml/min), probably trapping the small[17,18] ink pigment particles along with vehicle, which most likely resulted in the smaller color gamut.

However, the gravure production substrate printing via RIP software results in better spot color reproduction in highlight and mid-tone areas, providing better look and feel of print outcome. Manufacturer recommended proofing paper, on the other hand, has better spot color reproduction capability for all selected spot colors except for some highly saturated colors.

The EPSON StylusPro 4000 printer in combination with the RIPs produced the most accurate color reproduction among all selected print combinations. The RIPs' improvements over the over printer driver, because of the linearization process and ink limiting feature of the RIPs, allow an ink jet printer to distribute the right amount of ink onto the substrate. Moreover, with built-in color management functions, the color space can be defined in software at the prepress and RIPing stages to optimize the end results. These two commercially available RIPs provide options to accept recognized Pantone names or create custom spot

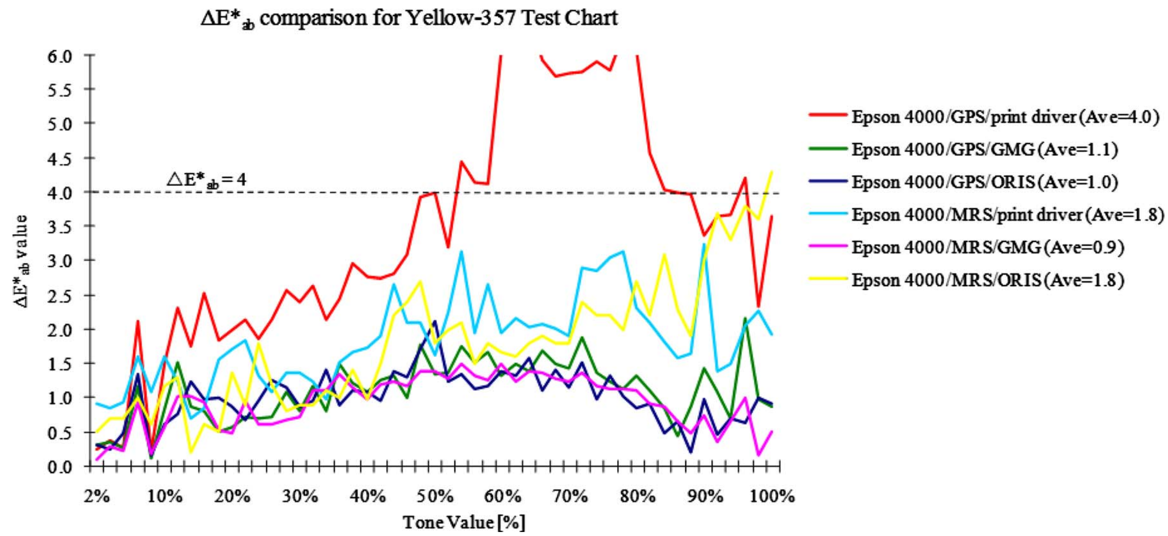

Figure 9. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Yellow-357 chart.

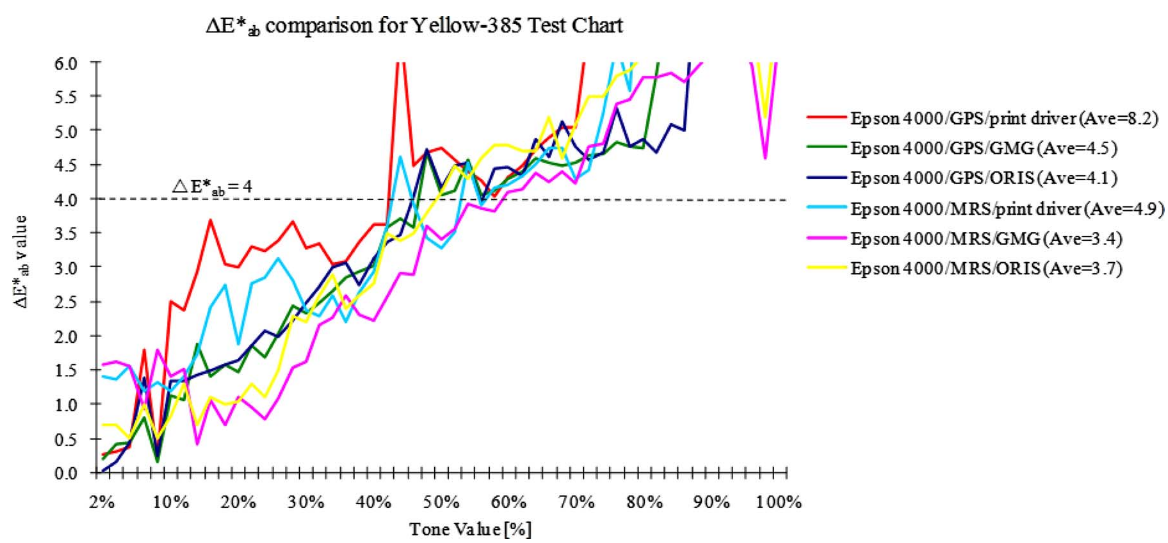

Figure 10. ΔE^*_{ab} comparison of original and printed $L^*a^*b^*$ values for Yellow-385 chart.

color libraries. They handle spot colors differently, by using their own "secret sauce" spot color matching function. However, both RIPs have feedback mechanism (reproducing spot colors back and forth) to do a better job of mapping spot colors. In this study, GMG RIP tends to have better spot color reproduction capability for blue, black, and red spot colors, whereas CGS ORIS RIP has better spot color reproduction capability in yellow spot colors. These results represent two different RIP controllers that were available to us. Though there were differences noted, the overall results were similar and we would expect similar results with other RIP software.

Apparently, a wide color gamut is necessary to produce accurate spot colors, regardless of which printer control software is used. Large ΔE^*_{ab} values obtained for some of the colors indicate that these colors cannot be reproduced properly by any of the print combinations. For some highly saturated colors or shadow tints in spot color test charts, trajectories traverse out of color gamut of the test printer contribute to higher ΔE^*_{ab} values. Digital printers employing extended color sets, such as Pantone Hexachrome[28] might be required to reproduce these highly saturated colors.

Other CMYK-based ink jet printers, such as the Epson StylusPro 2200 (Ref. 3) or 9800 (Ref. 29) are expected so show similar results to the 4000. An extended gamut ink jet printer, such as the Canon Pixma Pro 9000 printer, which has been shown to yield a large color gamut[30] on different substrates, would be of interest to study for reproduction of the spot colors discussed here.

Additionally, the success of any color reproduction is finally judged by human observers. Further visual assessments for these spot colors reproduction will be investigated.

ACKNOWLEDGMENTS

The authors thank Omnova Solutions, Inc., and National Science Foundation Grant No. MRI-0215356 for partial support for this work, and X-Rite, CHROMiX, Inc., GMG America and CGS Publishing Technologies for color measurement/management hardware and software donations.

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