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Decreasing metamerism of inkjet printed wood grain

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Abstract

Today, the competitive environment in the graphics communication industry is demanding the printer to produce good quality products within short periods of time. To ensure quality reproduction of print jobs, prototyping is necessary. Rotogravure cannot be used for prototyping, because of high manufacturing cost of gravure cylinders. Such challenges can be successfully tackled by use of relatively cheap and flexible printing processes, such as inkjet. Even though inkjet printing is a cost-effective way for prototyping, it has its own limitations, especially in the case of wood grain printing. Wood grain patterns need to be printed with a release coating and adhesive. Inkjet printers are incapable of printing either release coating or adhesive, because they require a certain amount of coat weight, not possible to deliver with inkjet printing. Inaccurate color reproduction, metamerism and incompatibility with release coat are the commonly seen problems during inkjet prototyping. The main aim of this study was to resolve problems such as metamerism and close color match of inkjet and gravure printed wood grain. A design of experiments (DOE) was carried out by using different factors such as gray component replacement (GCR) settings, release coat weight and use of tie coat to analyze their effect on metamerism. Custom created ICC profiles decreased the metamerism index (*MI*) and ΔE^*_{ab} significantly, when compared with the generic RIP printer profile. Manual GCR adjustment in addition to custom created ICC profiles decreased *MI* further, but at the same time increased ΔE^*_{ab} to some extent. Increased GCR settings had considerable impact on *MI*, which varied per color shade. The ICC profiles for the 7 g/m^2 release coat plus tie coat and 10.5 g/m^2 release coat plus tie coat substrate were created with 160 % total ink limit values, whereas 7 g/m^2 release coat and 10.5 g/m^2 release coat samples without any tie coat were profiled with 180 % and 200 % total ink limit, respectively. Higher total ink limit samples on 10.5 g/m^2 release coat with no tie coat showed the highest color gamut volume and lowest total ink limit, while 7 g/m^2 release coat plus tie coat showed the smallest color gamut volume. ANOVA statistical analysis showed that GCR setting was the most influential factor on *MI* followed by the use of the tie coat. Release coat weight was an insignificant factor for *MI*.

Keywords: inkjet, rotogravure, metamerism, color match, gray component replacement

1. Introduction and background

Currently, most of the décor or wood grain printing is done by the gravure printing process, due to its effectiveness in achieving consistent results in long production jobs. Simplicity and comparatively fewer set up parameters make gravure printing a more controllable process among other printing processes, but its costly image carrier manufacturing limits it only for long run jobs. However, the modern gravure industry has come up with narrow press technology, with cheaper image carriers (Mathes, 2016). But as market requirements are changing, customers are looking for more diverse wood grain designs, specifically in small quantities and variable color palettes. Gravure printing is cost-effective only if it is used for relatively long runs because of high cost for cylinder engraving. Hence, many printers are exploring other printing processes for wood grain prototyping and production of small quantity jobs. Every conventional impact printing process requires an image carrier that increases cost. Therefore, the inkjet printing process is one of the most feasible options to print wood grain patterns in a more cost-effective way, with flexibility of short quantity jobs (Wu, Fleming and Pekarovicova, 2008). However, inkjet printing has its own disadvantages, too. An inkjet printer uses process inks (Wu, Fleming and Pekarovicova, 2008), whereas gravure uses spot color inks to print wood grain patterns. Thus, color matching is one of the main concerns during inkjet prototyping and proofing of gravure printed jobs. Most likely, pigments used in inkjet inks are different from those used in gravure inks, which often leads to metamerism. Color matching issues can be resolved by implementation of color management systems into the process workflow. Metamerism can be minimized by using the same or somewhat similar types of pigments for both printing processes. It helps to get a closer spectral match between samples, but it is an expensive option. The greater is the difference between spectral power reflectance of two metameric samples, the greater is the color shift when illuminants or observers are changed. Though it is impossible to eliminate metamerism, it can be reduced to acceptable levels (Shendye, Fleming and Pekarovicova, 2010).

The degree of metamerism can be quantified (Shendye, Fleming and Pekarovicova, 2010) by calculating the metamerism index (*MI*). Metamerism indices can be of two types, general and special. General indices are spectral indices based on spectral differences between the members of the metameric pair and are independent of illuminant. Originally Bridgeman's Index (BMAN), presented by Bridgeman and Hudson (1969), was used to calculate the index but did not take into account the change in eye sensitivity in the whole visible spectrum of light. Nimeroff and Yurow indices were also used (Nimeroff and Yurow, 1965; Roy Choudhury and Chattergee, 1996). Even though the index is modified, if the spectral difference is averaged throughout the spectrum, it decreases the difference in spectral values and may be lessened as two ends of spectra are approached.

Therefore, it is important to calculate the difference, which is mainly dependent on illuminant and observer. Hence, it is more mathematically accurate to use a special MI than a general one. Special indices are based on XYZ tristimulus values. Especially for illuminants, there are two commonly used special metamerism indices: First, CIELAB special metamerism index, in which *MI* is calculated assuming the ΔE*ab color difference between the pair under the reference illuminant is equal to zero. Second, DIN 6172 metamerism index (Deutsches Institut für Normung, 2014), in which MI is calculated assuming the ΔE*ab color difference between the pair under reference illuminant is small but not equal to zero. Special metamerism indices should not be used if ΔE*ab between two samples under reference illuminant is more than 5 (Berns, 2008). CIELAB special MI can be calculated based on Equation 1:

$$MI = \sqrt{(\Delta L_{n_1} - \Delta L_{n_2})^2 + (\Delta a_{n_1} - \Delta a_{n_2})^2 + (\Delta b_{n_1} - \Delta b_{n_2})^2} \quad [1]$$

where n_1 is the first illuminant and n_2 is the second illuminant and Δ = Value of sample – Value of standard (HunterLab, 2008). Equation 1 is algebraically equal for both the CIE and DIN indices, but the interpretation is different. Under the CIE index, the colors perfectly match under the first, reference illuminant and small *MI* means they match well under a second illuminant. For the DIN index, the colors are assumed to match well under the reference illuminant and small *MI* means they match almost as well under a second illuminant. In either case, if the *MI* value is high, then there is a significant color difference between the sample pair under different illuminants.

Under Color Removal (UCR) and Gray Component Replacement (GCR) basically deal with color separations of four process colors (UCR&GCR, 1996). When three process colors (cyan, magenta and yellow) are overprinted, they should create black, but in reality, they give a brownish or muddy black appearance. Overprint black percentage can be replaced with black ink by UCR or GCR. The main difference between UCR and GCR is that UCR is a process of removal of cyan, magenta and yellow, wherever black is present, whereas GCR is process of replacing the gray component with black ink throughout entire image (UCR&GCR, 1996). The GCR is preferred over UCR because UCR deals with removal of CMY inks in dark and near neutral areas. Contrary to that, GCR is capable of replacing gray component from all colors in separation including highlights. Use of GCR has multiple advantages, such as fewer trapping problems, less dot gain fluctuation and fewer registration problems thanks to the use of only one ink instead of three.

Use of GCR also reduces consumption of ink substantially, reducing cost of an ink by as much as 50 % (Nimeroff and Yurow, 1965). Also, GCR improves color gamut, because as black level increases, color gamut volume also increases to some extent (Zhou, 2012; Spiridonov and Shopova, 2013). The color gamut volume is a volume in CIELAB space that represents the number of colors that the device (here inkjet printer) can produce with a tolerance of the $\sqrt{3}$ (Chovancova-Lovell and Fleming, 2009).

The main aim of this study was to resolve problems, such as metamerism and close color match between rotogravure and inkjet print. This makes possible accurate inkjet samples, proofs and short run production. To accomplish this goal, sample patches were printed on a Roland VS 540i inkjet printer and color matched to reference gravure printed patches with ΔE^*_{ab} less than 5. Custom created ICC profiles were compared with the default printer profiles. Manual GCR adjustment was done to assess its role in color matching. A Design of Experiments (DOE) was carried out by using different factors such as GCR settings, release coat weight and use of tie coat to analyze their effects on metamerism.

2. Materials and methods

Four gravure printed shades of wood grain, selected as reference patches, were printed as solid patches for ease of the measurement (rendered approximately in Figure 1). The CIELAB values of gravure reference patches were measured using an X-Rite Ci6x spectrophotometer. Four sample patches were constructed in Adobe Illustrator by assigning previously measured CIELAB values of the reference patches. Patches were labeled as Galaxy Oak, Smooth Grey, Hunter 655 and Rustic Maple, respectively (Figure 1).

Figure 1: Sample patches, with CIELAB values

A customized ICC profile was created using X-Rite 'i1Profiler' software. For customized ICC profile creation, the 800-patch color chart was automatically generated by i1Profiler software. Sample patches (Figure 1) were printed on the Roland VS 540i inkjet printer by applying the standard printer profile and customized ICC profile. Patches were once again printed by applying the customized ICC profile, but with additional manual GCR adjustment. In manual GCR adjustment, a percentage of CMY inks was replaced by the same percentage of K ink. The ΔE^*_{ab} and *MI* for the four patches were calculated and spectral graphs were compared to determine the initial significance of custom created ICC profile over default printer profile, as well as effectiveness of manual GCR adjustment and its effect on *MI*.

To analyze the influence of various factors on metamerism, a DOE was conducted by using three factors – GCR level settings, release coat weight, and use of tie coat (tie coat is an acrylic based clear ink used to promote adhesion between printed ink and adhesive). Table 1 shows number of trials and factors for the DOE experiments. We used this DOE method, a full factorial, since there are only 12 conditions and any smaller design would reduce the resolution of the design by confounding factors that need to be independent. Manual GCR adjustments were done in case of the trials with maximum GCR setting and compared with other DOE trials. For ease of analysis, 12 trials were divided into 4 substrate types based on release coat weight and use of tie coat. Then, each substrate was analyzed for 3 different GCR settings. The fundamental approach behind the use of factors 1 and 2 was to increase color gamut volume by improving total ink limit and to analyze the effect of increased color gamut volume on *MI*. Use of factor 3 was straightforward, i.e. to understand effect of increasing GCR setting on *MI*.

Trials 3, 6, 9 and 12 were conducted again with additional manual GCR adjustment in Adobe Illustrator to check its effect on *MI*. Spectral graphs were compared. Metamerism indices and ΔE^*_{ab} were calculated. Printed wood grain products were transferred onto the base wood by means of heat and pressure. Thus, all layers of the product needed to be printed in reverse order. All the layers of the wood grain in their respective order are shown in Figure 2.

Table 1: Trials for design of experiments

Trials	Factor 1: Release coat weight (g/m^2)	Factor 2: Use of tie coat	Factor 3: GCR levels
1	7.0	Yes	Minimum
2	10.5	No	Medium+
3	7.0	Yes	Maximum
4	10.5	No	Minimum
5	7.0	Yes	Medium+
6	10.5	No	Maximum
7	7.0	No	Minimum
8	10.5	Yes	Medium+
9	7.0	No	Maximum
10	10.5	Yes	Minimum
11	7.0	No	Medium+
12	10.5	Yes	Maximum

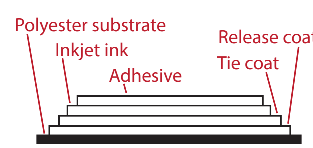

Figure 2: Schematic of wood grain layers printing

2.1 Release coat weight

After application of wood grain to the wood, release coat becomes the top layer of the wood grain that gives chemical and abrasive resistance to the wood grain product. In the absence of tie coat, the release coat is the first layer that comes in contact with the inkjet ink. Release coat weight determines the degree of chemical and abrasive resistance as well as gloss/matt finish of the product. Initially, substrates with 3 g/m^2 of release coat were used to create the customized ICC profile. Substrates were unable to take more than 100 % total ink limit value during media calibration for the Roland VS 540i inkjet printer. Cracks were observed after drying. The recommended minimum total ink limit as per printer manufacturer is 140 % to achieve acceptable print quality. To increase total ink limit value, substrates with higher release coat were used. Substrates with 7 g/m^2 and 10.5 g/m^2 release coat showed total ink limit higher than 140 %. Higher release coat substrates showed some cracking but it was not visible to naked eyes. Substrates with 7 g/m^2 and 10.5 g/m^2 release coat were able to accept 180 % and 200 % of total ink limit, respectively.

2.2 Use of tie coat

The vehicles in the inkjet ink make polymers in the release coat less elastic with the increased stress due to shrinking, causing cracks in a print area after drying. In wood grain printing, tie coat is usually used to promote adhesion between printed ink and adhesive, but it can also be used as an alternative to the original release coat. Tie coat contains low molecular weight polymers; hence it creates a relatively softer and more flexible layer of coating than release coat, which avoids cracking after drying. The use of tie coat leads to reduced rub resistance. Hence, tie coat is coated over release coat to maintain original rub resistance of the substrate as well as to avoid cracking. When substrates with tie coat over release coat were calibrated for Roland VS 540i inkjet printer, they showed no ink cracking. However, tie coat did not significantly improve total ink limit capability of substrate. Substrates with 7 g/m^2 and 10.5 g/m^2 release coat and with tie coat both were able to accept only 160 % for total ink limit.

2.3 Gray Component Replacement settings

Unlike older version of X-Rite profile making software Profile Maker 5.0, the new software i1Profiler does not specify percent of gray component replacement. Instead, it provides eight different steps under the name "Black Generation Curve". Eight GCR settings options are minimum, light, light+, medium, medium+, heavy, heavy+ and maximum. To analyze effect of the GCR, three settings of GCR (minimum, medium+ and maximum) were used in the design of experiments. The fundamental approach behind the use of different coat weight and tie coat was to increase color gamut volume by improving total ink limit and to analyze the effect of increased color gamut volume on *MI*. Use of the factor 3, GCR settings were used to understand their effect on *MI*.

3. Results and Discussion

The ΔE^*_{ab} comparison of inkjet and gravure reference patches showed color difference of less than 5 for all four wood grain patches (Galaxy Oak, Smooth Grey, Hunter 655, and Rustic Maple). Galaxy Oak color match with default printer profile, custom ICC profile, and manually adjusted GCR is illustrated in the Figure 3 under three different illuminants and Smooth Grey for the same conditions in Figure 4.

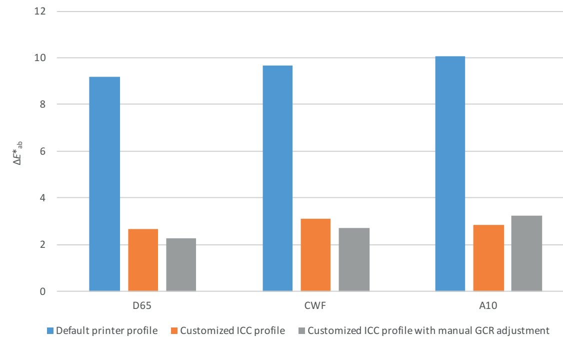

Figure 3: The ΔE^*_{ab} between gravure and inkjet printed Galaxy Oak patch using three different illuminants

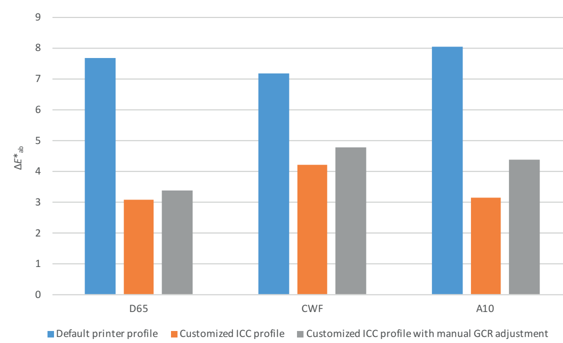

Figure 4: The ΔE^*_{ab} between gravure and inkjet printed Smooth Grey patch using three different illuminants

The customized ICC profile decreased color difference for all illuminants (Figures 3 and 4). On the other hand, manual GCR adjustment in addition to customized ICC profile increased color difference for all patches (not shown), except Galaxy Oak under D65 and CWF light sources (Figure 3). Metamerism Index comparison of all four sample patches showed that customized ICC profile significantly decreased *MI* for all illuminants (Figures 5 and 6), and unlike ΔE^*_{ab} difference, *MI* was decreased further by use of manual GCR adjustment in the custom ICC profile, except for Galaxy Oak, CWF & A10 (Figure 5). Spectral reflectance curves of gravure printed reference patches and inkjet printed patches with default printer profile, customized ICC profile and manual GCR adjustment were plotted for comparison. Spectral reflectance plots of all inkjet printed patches showed that custom created ICC profiles brought spectral reflectance curve closer to the reference gravure printed spectral curve, mainly because of improvement in ΔE^*_{ab} (especially improvement in lightness). Manual GCR setting, in addition to custom ICC profiles, improved spectral plot to some extent, in some cases. Spectral reflectance curves for Galaxy Oak are illustrated in Figure 7, and for Smooth Grey in Figure 8.

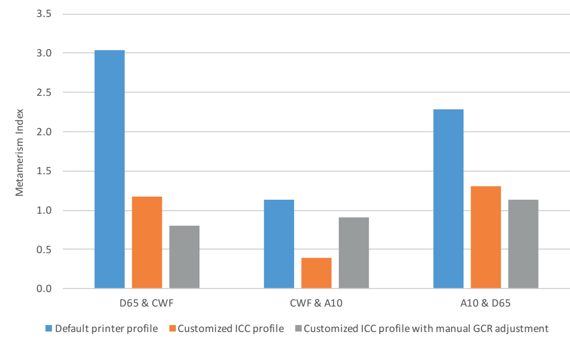

Figure 5: Galaxy Oak patch MI dependency on type of ICC profile used comparing three illuminant pairs

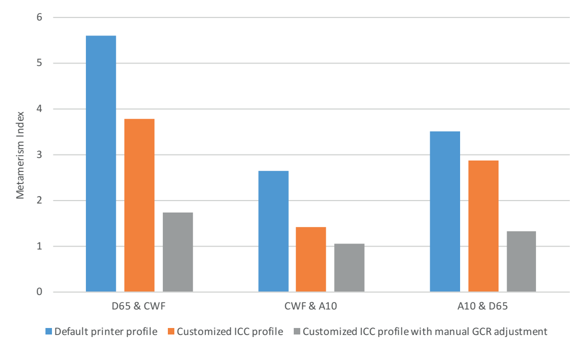

Figure 6: Smooth Grey patch MI dependency on type of ICC profile used

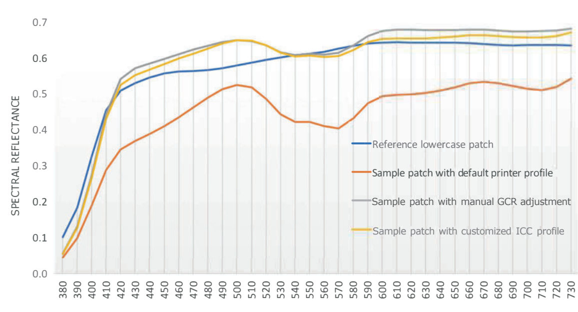

Figure 7: Galaxy Oak patch spectral reflectance curves

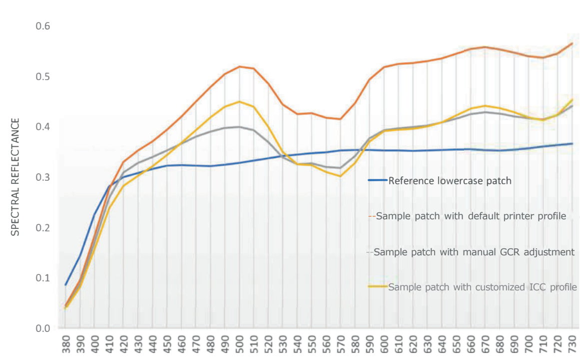

Figure 8: Smooth Grey patch spectral reflectance curves

To analyze the effect of GCR settings on ΔE^*_{ab} and *MI* simultaneously, GCR settings were plotted on the X-axis, whereas both ΔE^*_{ab} and *MI* were plotted on the Y-axis. For all types of substrates, color patches, and all illuminants (D65, CWF and A10), the minimum GCR setting showed the highest *MI*, whereas the maximum GCR setting showed the smallest *MI* (Figures 9 and 10). The ΔE^*_{ab} and GCR settings did not show any significant correlation between each other except for the Smooth Gray patch. For the Smooth Grey patch, ΔE^*_{ab} decreased significantly with increase in GCR settings; contrary to that, for rest of the patches ΔE^*_{ab} fluctuated by 1–2 ΔE^*_{ab} range. Among all patches, Smooth Grey patch showed the highest improvement in *MI*, Hunter 655 showed least improvement, whereas Galaxy Oak and Rustic Maple showed slightly more improvement than Hunter 655; data are given elsewhere by Turke (2016). For all trials, manual GCR adjustment neither improved *MI* nor ΔE^*_{ab} to a significant extent.

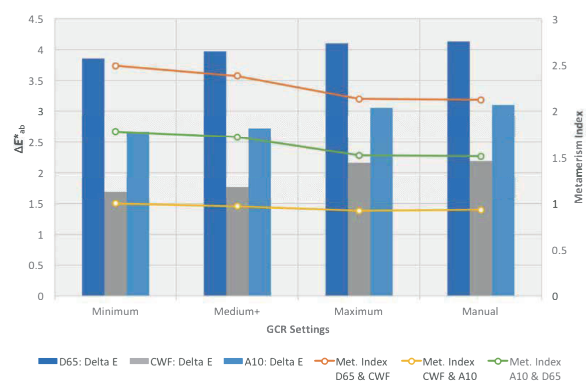

Figure 9: The ΔE^*_{ab} & MI of Galaxy Oak patch with 7 g/m^2 release coat plus tie coat

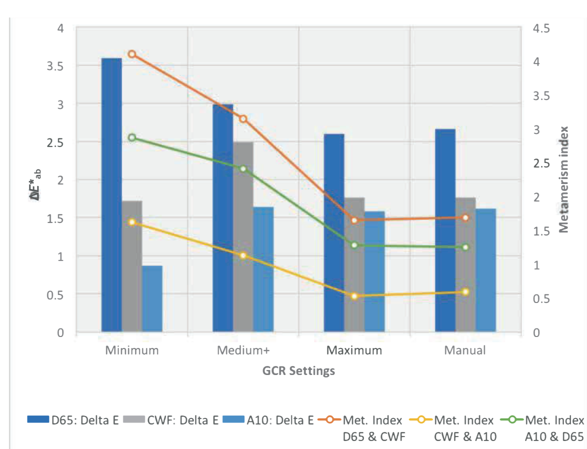

Figure 10: The ΔE^*_{ab} & MI of Smooth Grey patch with 7 g/m^2 release coat plus tie coat

As manual GCR adjustment did not show any significant improvement in *MI*, it was not included in spectral distribution curve comparisons in Figures 11 and 12.

Spectral reflectance of selected gravure printed reference patches and inkjet printed sample patches with Minimum, Medium+ and Maximum GCR setting are plotted in Figures 11 and 12. Spectral graphs of all color patches crossed reference patches spectral reflectance curve patch thrice and are thus considered to be metameric. Even though color patches were metameric, spectral reflectance curves of maximum GCR setting were closest to the spectral curve of reference patch, followed by medium GCR setting and minimum GCR setting spectral curves, respectively. Among all patches, the Smooth Grey patch showed the highest improvement in spectral curves (Figure 12), and Hunter 655 showed the least improvement, whereas Galaxy Oak (Figure 11) and Rustic Maple (data not shown) showed slightly more improvement than Hunter 655.

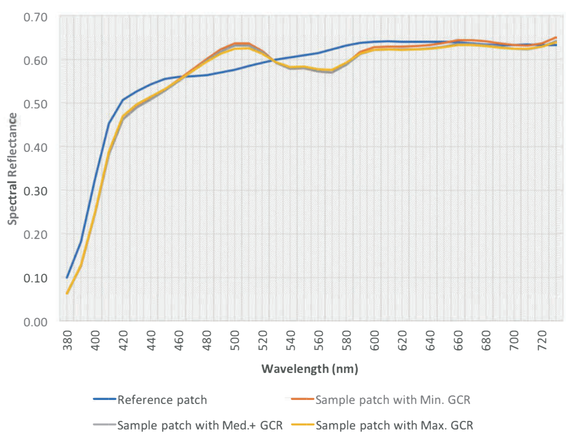

Figure 11: Spectral curve of Galaxy Oak atch with 7 g/m² release coat with different GCR settings

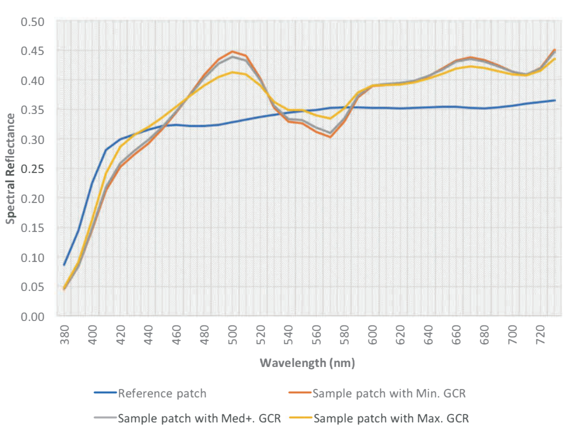

Figure 12: Spectral curve of Smooth Grey patch with 7 g/m² release coat with different GCR settings

Further, color gamut for combination of variables was examined (Table 2). The ICC profiles for the 7 g/m² release coat plus tie coat and 10.5 g/m² release coat plus tie coat substrate were created with 160 % total ink limit values, whereas 7 g/m² release coat and 10.5 g/m² release coat substrates, without any tie coat, were profiled with 180 % and 200 % total ink limit, respectively. As expected, the highest total ink limit substrate, i.e. 10.5 g/m² with no tie coat, showed the highest color gamut volume, while the lowest total ink limit substrate, i.e. 7 g/m² plus tie coat, showed the smallest color gamut volume. Apparently, the tie coat stopped cracking of the ink, but restricted the spectral reflection from ink films, which along with low total ink limit value of around 140 % caused drastically decreased color gamut volume (Table 2).

Table 2: Color gamut volume comparison

Sample	Release coat (g/m²)	Tie coat	Color gamut (CCU)
1	7.0	Yes	138 827
2	10.5	Yes	147 850
3	7.0	No	304 802
4	10.5	No	357 646

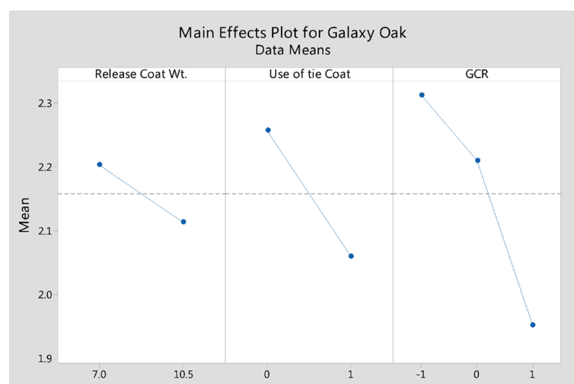

Figure 13: ANOVA main effect plot for Galaxy Oak patch MI

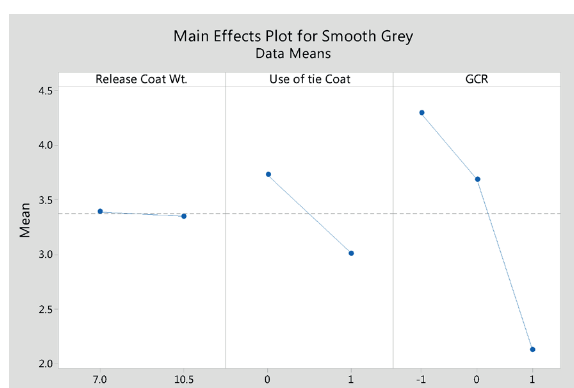

Figure 14: ANOVA main effect plot for Smooth Grey patch MI

Analysis of variance (Turke, 2016) was conducted for *MI* obtained from 12 DOE trials for all patches. Metamerism index ANOVA results for Galaxy Oak are illustrated in

Figure 13 and for Smooth Grey in Figure 14. Resulting *P*-values showed that for all patches, except Hunter 655, GCR settings significantly influenced *MI*, followed by tie coat. For Hunter 655 patch (data not shown), use of tie coat was the most significant factor. However, release coat weight had an insignificant effect on the *MI* response. This indicates that after a certain limit, there is no value in increasing the release coat weight. Based on the results, this value is about 7 g/m^2. The comparison of main effects plots for all patches suggested that use of tie coat with maximum GCR setting would give the lowest *MI* for every spot color. None of the two factor interactions were significant for any of the spot colors. Full ANOVA results, including statistics, are presented by Turke (2016).

4. Conclusions

The ΔE^*_{ab} comparison of inkjet sample patches and gravure reference patches show that the customized ICC profiles significantly decreased color difference for all illuminants. Also, custom created ICC profiles decreased the *MI* and ΔE^*_{ab} difference significantly, when compared with the generic RIP printer profile. Analysis of spectral reflectance curves justified the significance of custom created ICC profiles over generic RIP printer profile. Manual GCR adjustment in addition to custom created ICC profiles decreased *MI* further, but at the same time increased ΔE^*_{ab} color difference to some extent. Design of experiments consisting of 12 trials was conducted using different multi-level factors. Results showed that increased GCR settings had considerable impact on *MI*, and it varied per color shade. Darker patches showed the highest reduction in *MI*; contrary to that, the response to GCR settings by lighter patches was none or insignificant. Analysis of spectral reflectance showed similar results for dark and light patches of colors. The GCR settings neither improved nor deteriorated color difference, and ΔE^*_{ab} color differences fluctuated up and down in range of 1–2 ΔE^*_{ab} units. The ICC profiles for the 7 g/m^2 release coat plus tie coat and 10.5 g/m^2 release coat plus tie coat substrate were created with 160 % total ink limit values, whereas 7 g/m^2 release coat and 10.5 g/m^2 release coat substrates without any tie coat were profiled with 180 % and 200 % total ink limit, respectively. As expected, the highest total ink limit substrate i.e. 10.5 g/m^2 with no tie coat showed the highest color gamut volume and the lowest total ink limit substrate i.e. 7 g/m^2 plus tie coat showed the smallest color gamut volume. Apparently, the tie coat stopped cracking of the ink, but restricted the color gamut volume of the substrates drastically because of low total ink limit value around 140 %. The ANOVA analysis showed that GCR setting was the most influential factor followed by use of the tie coat. Release coat weight was an insignificant factor. In addition to that, the main effects plot showed maximum GCR settings with the use of tie coat would be the best combination of those tested to get maximum reduction in metamerism index.

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