Effect of Optical Brightening Agents and UV Protective Coating on Print Stability of Fine Art Substrates for Ink Jet

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Abstract

Non-impact printing is gaining wider acceptance in the printing world, with one of the rapid growing applications being fine art color printing technology. With the right amount of artist's imagination and combination of the right substrate and ink, it is possible to create a piece of art work that will last for a long time.

This study includes a comprehensive look into ink/substrate combinations. The choice of proper substrate and coating, ink jet inks, together with some form of protection for ink jet printouts, is discussed here. Substrates with special ink jet receptive layers, with and without optical brightening agents (OBAs), were chosen for this work. The correlation between substrate's characteristics and final print performance was investigated. Ink stability of prints with time was observed and lightfastness tests were performed in order to evaluate the stability of printed color patches on specific substrates. A special UV coating was applied to study its protection level. Results of accelerated lightfastness tests for the different substrates are interpreted in terms of change of color gamut volumes and ΔE.

Introduction

The ability of pigment based inks to maintain accurate color strength over time due to light exposure and subsequent fading is as important as the printed color itself, especially, when the industry is so fixatedly bound to color precision and long term print permanence. Resistance to fading is significant in several situations. The need for longer storage times drives the industry towards inks and papers that should be reliable in their lightfastness performance.[1-5]

Most types of ink jet ink comprise dyes or pigments as colorants and an ink carrier, e.g., water or solvents. The type of ink to be used is also substantially determined by the properties of the substrate, the surrounding conditions of the print substrate, e.g. light, wear, weather resistance, and the drying process required during printing with different printing systems. [6]

The current market is driven by customers' requests. In the case of substrates, the brighter or whiter paper will be more expensive, but will give the customer expected appearance. For this purpose the papermakers stack specific chemical substances into a paper base and coating. These substances are called optical brightening agents (OBAs) or fluorescent whitening agents (FWAs). [7,8] Surprisingly, a recent study on papers for digital printing conducted by a team at the School of Print Media at Rochester Institute of Technology and Institute of Paper Science and Technology at Georgia Institute of Technology showed that the main factors that influence users' decision to pick up the right substrates was their runnablility and printability.[9] A performance related factor was found to be more important than substrate appearance factor, the leading characteristics being toner/ink adhesion, uniformity and surface finish among all.[9] Another study supports the fact that paper's appearance related characteristics, such as brightness and whiteness, do not necessary produce the best print performance results overall.[10,11]

Experimental

We chose different examples of high end fine art ink jet coated papers. All of these are recommended for use with ink jet pigmented ink sets, such as Epson's UltraChrome pigment based inks. All of the ink jet papers are bright white or natural white, depending on the OBA presence, acid and lignin free, water-resistant fine art paper made from 100% cotton fiber. The sample names used in the testing follow:

Ink jet 100% cotton papers with OBA:
- *Hahnemühle Photo rag*
- *Sterling smooth Fine Art Paper (Sterling I)*
- *Elegance Velvet Fine Art Paper*
- *Somerset Velvet smooth*
- *Somerset Velvet textured*

Ink jet100% cotton papers with no OBA:
- *Sterling Rag (Sterling II)*
- *Sterling Rag Platinum (Sterling III)*
- *Arches Infinity smooth*
- *Illuminata Photo Rag smooth*
- *Arches Infinity textured*

Inkjet canvases:
- *Brilliance Chromata White with OBA (Brilliance I)*
- *Brilliance Natural OBA-Free (Brilliance II)*

An Epson Stylus PRO 4000 printer with PowerRIP X software was used to produce the CMYK outputs for further testing. The PowerRIP X software has been shown to provide the full color gamut of the printer.[13] In order to create a new ICC profile for the printer/substrate combination, the output options were set to "Not Color Managed". For higher ink load the 1440 dpi resolution and Premium glossy photo paper for media were chosen.

For testing the substrates, Lab values of the printed charts were measured with a spectrophotometer. First, the stability of pigment on the substrates was investigated. The ECI 2002R chart was printed on two different substrates and the Lab values were gathered in the following sequences: 0 hr, 1 hr, 2 hr, 3 hr, 6 hr, 18 hr, 24 hr, and 48 hr. Measured values were used to generate ICC profiles for each substrate. Gamut volumes were calculated from the corresponding ICC profiles. The ink/substrate combinations reach constant values about 6 hours after outputting the prints. Taking into consideration fact that the stable image is obtained 6 hours after printing, the testing of the color stability should start at least 6-12 hours after printing. No linearization of the printer was conducted, it has been found that the process does not improve the final print quality and may even decrease the amount of ink deposited on the media and thus alter the total color value that could be achieved.[12]

It was found that samples claiming no OBA existence in their composition did not exhibit peaks in the blue region of the visible light and thus no presence of brightener. Unexpectedly, the one of the substrates, Hahnemühle Photo Rag, that does not claim no OBA presence, and thus suggested to be an OBA paper, did not show presence of brighteners based on the spectral data.

The permeability and roughness of the sheets were measured using a Parker Print Surf (PPS) tester (TAPPI T555 PM-94) at different clamping pressures (Table 1). The permeability coefficient was calculated using the Pal equation derived from Darcy's Law.[13]

$$\textit{Permeability Coef., } K\ (\mu m^2) = 0.048838 * \textit{PPS Porosity, } Q\ (ml/min) * \textit{Caliper, } L\ (m) \qquad (1)$$

Table 1. Porosity, Roughness and Permeability results for the ink jet substrates.

	PPS Porosity		PPS Roughness	Permeab. Coeff.
	500*	1000*	1000*	
Paper:	(ml/min)		(microns)	(μm^2)
WITH OBA				
Hahnemühle	910.8	897.9	7.0	0.024601
Sterling I	207.1	191.8	8.5	0.004847
Elegance	998.0	936.3	8.6	0.031977
Somerset sm.	786.6	757.8	8.8	0.016255
Somerset text.	1634.0	1524.0	11.9	0.042849
No OBA				
Sterling II	111.3	102.7	8.2	0.001604
Sterling III	119.3	113.3	6.0	0.001638
Arches sm.	4.1	1.1	7.1	0.000025
Illuminata sm.	239.2	220.7	6.9	0.006179
Arches text.	12.1	1.8	10.7	0.000047
Canvases				
Brilliance I	7.5	1.7	8.7	0.000068
Brilliance II	36.0	5.5	12.5	0.000169

TAPPI brightness is used as a measure of the reflectance of papers at specific wavelengths and is specified in TAPPI Method of Test T452, "Brightness of pulp, paper and paperboard (directional reflectance at 457 nm)." Opacity is a measure of media ability to avoid penetration of light from one side to the other, expressed as a ratio of the single sheet reading to the reference one. The standard procedures are described in TAPPI test method T 425 om 01 Opacity of paper with 15/d geometry, illuminant A/2°, 89% reflectance backing and paper baking (Table 2).

The CIE Whiteness was calculated form obtained X, Y and Z data as follows[14]:

$$W_{CIE} = Y + 800(x_n - x) + 1700(y_n - y), \qquad (2)$$

where: $x = X/(X+Y+Z)$,

$y = Y/(X+Y+Z)$,

$x_n = 0.3138$, and $y_n = 0.3310$ for $D_{65}/10$.

In order to obtain the large amount of data the ECI 2002 Random CMYK Chart was printed on all the substrates with the Epson Stylus printer. First, the Lab values of the tested printouts are measured and color gamuts were calculated before fading procedures. Then, the printed charts were submitted to the 48 hours exposure in the fademeter. The Suntest CPS+ tabletop xenon exposure system was equipped with an 1100 watt air cooled xenon arc lamp light source. The samples were submitted to 129,600 kJ/m^2 of energy over 48 hours (@ 765 W/m^2) with the uncoated quartz glass filter configuration and measured again. The temperature in the chamber was 70°C. This represents about 4.5 months (June) of daylight exposure in Florida.[15]

Table 2. Brightness, Whiteness and Opacity results for the ink jet substrates.

	TAPPI Brightness	CIE Whiteness	TAPPI Opacity
Paper:			()
WITH OBA			
Hahnemühle	91.01	88.21	98.4
Sterling I	93.55	93.11	98.3
Elegance	93.55	88.88	98.9
Somerset sm.	94.17	92.26	97.5
Somerset text.	92.86	92.99	97.8
No OBA			
Sterling II	90.63	80.93	95.8
Sterling III	90.09	79.63	96.3
Arches sm.	90.91	82.23	98
Illuminata sm.	89.65	78.16	99.1
Arches text.	90.17	80.23	96.4
Canvases			
Brilliance I	93.78	94.4	99.6
Brilliance II	90.94	92.51	99.1

In all cases the color gamut volume changed from the initial testing time to the short submission to the radiation (Figures 1 and 2). The change in volume and percentage of loss can be calculated as a difference between the gamut volume value before and after the fading. For representation of color change caused by fading, ΔE values, the color difference before and after the short term fading tests, can also be calculated (Table 3).

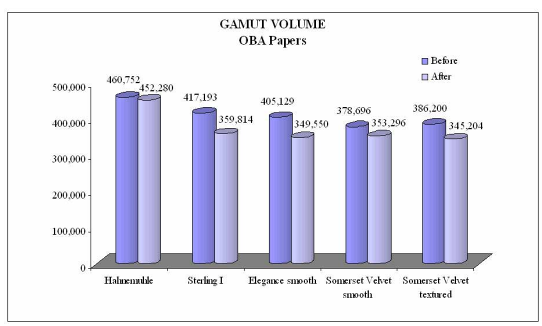

Figure 1. Gamut volume of ink jet papers that claim to contain OBAs

To be able to obtain an evenly spread post print coating layer on a print, a foam roller applicator or spraying system must be used. In order to verify the manufacturer statements[16], one of the OBA substrates (Sterling I) with the larger color gamut (417,193) and the highest loss of color performance (14%) with time was submitted to the test. As claimed, the applied UV protective coating should cause an increase in the gamut volume, even before the fading test because of the higher densities to be reached. The protective effect of the coating should also appear as a decrease of the gamut volume loss after the submission to the fading test (Table 4).

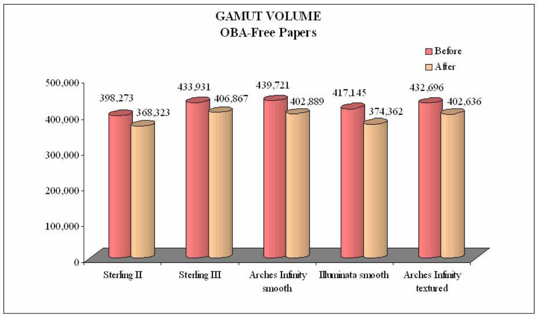

Figure 2. Gamut volume of ink jet OBA- free papers.

Table 3. Gamut volumes before and after fading, delta volume, % of loss, and delta E, color difference for all of the ink jet substrates.

	Gamut Volume				
Paper:	**Before**	**After**	**Delta**	**Loss**	**Δ E**
OBA					
Hahnemühle	460,752	452,280	8,472	2	4.8
Sterling I	417,193	359,814	57,379	14	4.8
Elegance	405,129	349,550	55,579	14	6.2
Somerset sm.	378,696	353,296	25,400	7	5.5
Somerset text.	386,200	345,204	40,996	11	9.6
o OBA					
Sterling II	398,273	368,323	29,950	8	5.1
Sterling III	433,931	406,867	27,064	6	3.1
Arches sm.	439,721	402,889	36,832	8	4.5
Illuminata sm.	417,145	374,362	42,783	10	5.8
Arches text.	432,696	402,636	30,060	7	5.1
anvases					
Brilliance I	416,453	285,052	131,401	32	13.9
Brilliance II	412,196	379,744	32,452	8	4.8

Table 4. Gamut data for Sterling smooth Fine Art paper with and without post print coating.

	Gamut Volume				
Paper:	**Before**	**After**	**Δ**	**Loss**	**ΔE**
Sterling I	417,193	359,814	57,379	14	4.8
Sterling I w/coating	415,864	347,671	68,193	16	8.2

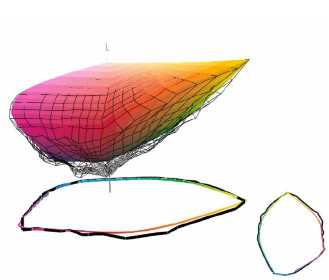

Figure 3. 3D and 2D gamut comparison for Sterling smooth Fine Art paper with (black) and without (true color) post print coating.

On the contrary, the gamut volume is virtually unchanged from the uncoated print before the fading test and the loss in gamut volume is greater for the coated one than the uncoated. Furthermore, the coated sample shifts the gamut boundary towards lower L values (Figure 3).

Discussion

Different ink jet substrates can provide the consumer with a wide range of properties, even though they all claim to be suitable for a given printer. The different media provide consumers with special receptive coating layers and thus attain a wide range of PPS porosity and permeability values. The smoothness of the investigated substrates falls into a very narrow gap (6–12 microns of PPS roughness). Usually, the textured materials exhibit rougher surfaces and thus give higher roughness readings (Table 1). Since permeability is strongly dependent on PPS porosity readings of the substrate, the permeability coefficients also vary significantly within the sample sets. On the average, the OBA-free substrates were found to be having lower PPS porosity and a smoother surface finish when comparing to the substrates containing OBAs (Table 1).

As expected the OBA substrates can provide one with a brighter and whiter look of the substrate (Table 2). The Hahnemühle Photo Rag, which was claimed to include OBAs, was found to be an exception. This substrate did not show a significant peak in the blue region of the visible light spectrum, and thus presence of brighteners. Also, the brightness and whiteness values were found to be the lowest from all the OBA samples, being closer to the OBA-free ones. As expected, the OBA-free samples possess lower brightness and whiteness due to the lack of OBAs (Table 2). In case of opacity, the OBA-free samples were able to reach high readings for Arches Infinity smooth and Illuminata smooth fine art papers (98.0 % and 99.1 %, respectively).

Another way to look at the substrate's performance is to gather L*a*b* values from patches included in the test chart, create a profile, which will characterize the ink/substrate combination for a specific printer, and calculate gamut volume for specific substrate/ink combination. When using the same setup and the same ink set, the color performance is only dependent on substrate properties, most of the time the physical ones. As seen from figures 1 and 2, the highest gamut volume number was achieved using Hahnemühle Photo Rag (OBA), followed by Arches Infinity smooth (OBA-free) and Sterling Rag Platinum (OBA-free) substrate, respectively (Table 3). Surprisingly, two of three substrates that were able to achieve the highest gamut volumes were OBA-free paper. Even more interesting is that the Hahnemühle Photo Rag substrate achieved the highest gamut volume from all the samples with brightness and whiteness values very close to the OBA-free ones, which makes us think there is insignificant presence of OBAs, if any, in this substrate. As stated before, there is was no correlation found between the optical properties of the substrate, e.g. brightness, whiteness and opacity, and the specific range of colors that can be produced on such substrates. Based on these facts and results, it is assumed that the presence of optical brightening agents doesn't necessary mean higher color output.

The effect of OBAs is vital when exploring the longevity and lightfastness of the prints. After submission to radiation, the gamut volumes decreased for all the samples as seen from the figures 1 and 2 and table 3. The color performance change can be presented two different ways, as a % of gamut volume loss before and after fading test, and as a ΔE, a color difference, before and after fading. The most negligible loss of the gamut volume after fading was calculated for the Hahnemühle Photo Rag (OBA), followed by Sterling Rag Platinum (OBA-free) substrate, Somerset Velvet smooth (OBA), and Arches Infinity textured (OBA-free), respectively. On the other hand, the smallest color difference, ΔE, was found for Sterling Rag Platinum (OBA-free), Arches Infinity smooth (OBA-free), and Hahnemühle Photo Rag (OBA) substrate, respectively (Table 3).

The investigation of the UV post print coating did not show the claimed protective properties. Definitely, the gamut boundaries shift towards the darker areas of the spectrum and thus the lighter areas become affected as well (Figure 5). The protective level of this coating is questionable, since the gamut volume loss and ΔE color difference do not verify the claimed results (Table 4). Contrary, the presence of UV light is necessary for OBAs to activate and emit light to higher wavelengths in order to create the whitening effect. The UV coating is suggested for use by manufacturers because of its great ability to inhibit ultraviolet light hitting the substrates in order to protect OBAs from fading. This controversy brings a question of real purpose of the coating. Is there a reason to apply a coating that will disable the OBAs?

Conclusions

The output should be evaluated in terms of overall printer capability, not only in terms of a substrate quality (price, grade, optical and physical properties), the type of ink set, and the basic level of color reproduction (density, Lab values). All these should be taken into consideration together with other very important factors, such as the length of time required for colors to stabilize, the image permanence of the printout, and the ink levels in terms of color gamut surface and volume with which a wide range of media can be characterized.

The optical properties, physical properties and color performance of different substrates with special ink jet receptive coating layer with and without optical brightening agents (OBAs) were investigated in this work. There was no correlation found between the optical performance of the substrate, brightness and whiteness, and the ability to display all possible colors in terms of gamut volumes. It was found that the OBA-free substrates were capable of demonstrating larger gamut volumes when compared to the OBA containing substrates.

Print stability was observed with time and lightfastness tests were performed in order to evaluate the stability of printed color patches on specific substrates. The smallest color difference, ΔE, was found for two OBA-free substrates and arguable Hahnemühle Photo Rag. In terms of the least loss of color data, again the OBA-free substrates showed the best lightfastness performance.

Lastly, a special UV coating was applied to study its protection level. Since the gamut volume loss and ΔE color difference did not show the expected favorable results when UV coating was applied, the alleged protecting role of this coating is questionable.

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