Print Quality Evaluation of Silica-Based Ink Jet Paper Coatings: Sheet vs. Continuous Coaters

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Abstract

Various protocols for measuring the quality of color ink jet prints have been developed. An automated image analysis system has been constructed and programmed to evaluate print quality measures including color gamut, black optical density, print mottle, bleed, linewidth, raggedness, and sharpness. After defining print quality evaluations a silica-based coating was coated onto paper using the continuous coating methods of a puddle press, a rigid blade coater, and a metered size press. Using the same coating, a laboratory bench-top coating unit was used to generate single sheets of papers at equal coat weights to the continuous scale. Comparisons were made between laboratory sheets and continuously generated sheets using image analysis derived measures of print quality. The information gained is useful in deciding whether laboratory screening of various coatings formulations will be of use in projecting commercial print quality. In addition, while generating this information, the benefits of a silica gel-based coating were evident.

Introduction

Ink jet printing is a high-growth segment in today's digital printing marketplace. Paper based media for ink jet printing range from uncoated office papers to photo quality high-gloss coated sheets. Coating materials range from sizing with water-soluble polymers, such as starch, to pigmented systems, including silica gel and other inorganic pigments, to glossy polymer based coatings.

Within this market there is a focus on matte papers that have been optimized for ink jet printing. These papers provide vivid colors and clean definition lines. Commonly, silica-based materials are employed as pigments to create coatings that satisfy the requirements of this segment. These coatings can be applied offline onto uncoated, rolled paper, or online directly after the wet-end of the paper making process.

Methods for comparative assessment of print quality have been detailed for plain papers,[1-4] various sizing treatments[5-9] and for silica-based coatings.[10-12] In this work, print quality measures are presented that can be used to evaluate silica-based coatings for high quality, matte, color, ink jet printing.

In evaluating the performance of various paper coatings, a key issue is moving a coating from sheet coater, to pilot coater, to commercial scale machinery. To limit expensive and complicated commercial trials, it is important to have laboratory screening techniques that predict the print quality behavior of a coating. Using a set of print quality measures, the issue of the extent that sheet coating procedures are indicative of print quality enhancements gained by using silica-based coatings on offline and online coaters can be examined.

By comparing the print qualities of coated sheets vs. the uncoated base paper, the equally important issue of the degree of print quality improvement generated by a silica-based coating can be defined.

Measures of Color Ink Jet Print Quality

With respect to ink jet print quality, the previously cited studies typically measured the absorption/spread properties of black ink printed on papers with various treatments. The advent of automated image analyses employing common cameras, robotic tables, and standard PC's has enabled the industry to generate large amounts of print quality data on sheets with color ink jet images. A number of commercial image analysis based systems have been developed for the analysis of print quality.[13-16] Although deciding which attributes to measure and how much each should be weighted in terms of significance can be arbitrary, a number of measurements used in the industry have generated interest and comment. Print quality attributes chosen for this study include:

Color Gamut Vector Sum:

In this measure, CIE L*a*b* (standard method of the Commission International de l'Eclairage, also known as CIELAB) measurements are obtained on 100% filled color blocks of cyan, magenta, yellow, red, green, and blue (C, M, Y, R, G, B). Plotting a* vs. b* on an x,y plot allows for the generation of vectors which represent the chroma of that individual color. The lengths of these vectors were summed to create a parameter named vector sum. A higher vector sum is desirable.

Black Optical Density:

Black intensity was measured by the change in reflectance as given by Equation 1:

$$OD = log_{10} (I_i/I_r) \quad (1)$$

where I_i and I_r are the incident and reflected light intensities, respectively). Higher black optical density is desirable.

Print Mottle:

Mottle is visualized by a blotchy, uneven look in solid image areas. Mottle was characterized by a modified ISO 13660 procedure. In the procedure a 2 cm x 2 cm block of a blue, green, or black color block is broken into a 10 x 10 grid. Each element in the grid was measured for its average gray value. The gray values were averaged to provide an overall average and standard deviation for the entire block. The standard deviation defines print mottle. Green print mottle was chosen to be representative due to its distinctiveness to the eye. Lower standard deviations are desirable.

Bleed:

Bleed is a measure of the tendency of black ink to bleed into yellow ink when the two are applied in adjoining areas. Bleed was measured on positive (black) horizontal and vertical lines with linewidths of 8, 4, 2, and 1 pixels. To quantify bleed, the linewidth of a black line transcending the border of a yellow box on white was measured in microns in both the yellow and white areas. The difference, which defines the bleed, was obtained by subtracting the linewidth in the white from the linewidth in the yellow. Under this definition, both positive and negative values for bleed are possible. A bleed value of zero is desirable. The bleed of a horizontal, 8 pixel line was chosen to be representative.

Linewidth:

Linewidth is a measure of the tendency of ink to spread laterally over the surface of a paper. To determine the linewidth for a positive image, the image analyzer locates the edge of the line where a gradient from whiteness to blackness occurs and measures distance across the line until whiteness begins again. The inverse would be done to define the linewidth of a negative (white) line. The result is reported in microns. For a given line target, a lower value of linewidth is desirable. Linewidth has been measured for 1, 2, 3, and 4 pixel horizontal and vertical lines for both positive and negative images. The linewidth of a 4 pixel, positive, horizontal line was chosen to be representative.

Raggedness:

Raggedness (Tangential Edge Profile) is the average displacement from the best fit edge line of the individual points used to define the line, with the value reported in microns. A zero value is most desirable. Raggedness was measured for each of the 16 positive/negative, horizontal/ vertical, pixel combinations detailed above. The raggedness of an 8 pixel, positive, horizontal line was chosen to be representative.

Sharpness:

Sharpness (Normal Edge Profile) is a measure of the spatial transition from a light area to a dark area and is measured in pixels. A low sharpness value indicates a sharper transition from background to printed area. Lower sharpness values are desired. Sharpness was measured on horizontal and vertical lines. Horizontal sharpness was chosen to be representative.

Experimental

Silica-Based Coating:

A silica-based coating for ink jet papers available from Grace Davison was used for all studies. The formulation was used as-is, with the exception of performing water dilution to the specified Brookfield viscometer value required for handling on any given piece of coating equipment.

Base Paper:

Two different base papers were employed at the continuous coater facilities. In order to make comparisons to sheet drawdowns, uncoated papers from the same facility were coated in the laboratory.

Coat Weights:

Coat weights of dried and room humidity equilibrated papers were measured by mass difference between coated sheets and uncoated sheets of the same base paper. Coat weights are expressed in grams per square meter (gsm) for a single side.

Sheet Coater:

A lab coater manufactured by RK Print-Coat Instruments, Ltd. (Model K202) was employed. This unit “draws down” a wire-wound rod over the paper surface, leaving a layer of coating behind. For the coat weights of interest to this study, the rod delivering the lowest wet film thickness generally left a coat weight higher than desirable. Thus, the coating was diluted and drawdown and dilution were repeated iteratively until the desired coat weight target was attained. Papers coated by this method are referred to as “laboratory drawdowns”.

Puddle Press:

A pilot scale Dixon coater was used. In this configuration, puddles of coating are contacted with both sides of the paper at the nip, generating a coating on both sides. A fixed input viscosity of 200 cP Brookfield was used.

Rigid Blade Coater:

A pilot rigid blade coater was used. Variation of the blade angle was used to generate two different coat weights. A sheet coated on one side was generated.

Metered Size Press (MSP):

A rod metered size press was used at line-speeds approaching commercial rates. Coating was metered by a rod to a level desirable for high print quality. Variance of the coat weight by dilution or changing of the rod was not attempted with this equipment. A sheet coated on one side was generated.

Print Quality by Image Analysis:

An ImageXpert™ (ImageXpert, Inc.) automated image analysis system was employed to measure the print quality parameters discussed above. Algorithms to convert raw data into the parameters discussed above were custom derived, as were the color print targets.

Ink Jet Printer:

An HP 970 Cxi ink jet was used to generate custom print targets for image analysis. A dedicated 450 MHz Pentium III class Windows-based PC system printer running Corel Draw was used to drive the printer.

Methodology of the Study

Before conducting the study, a reproducibility determination of the experiment from coating through image analysis was performed. This establishes the ability to determine when measurements are statistically different from one another. In order to gain an understanding of whether the laboratory drawdown method of paper coating was indicative of continuous coating methods, the following methodology was employed.

1. The silica-based coating was run on the continuous machine. The finished paper was taken-up onto rolls.
2. 8.5 inch x 11 inch sheets of coated and uncoated paper were cut from the same roll. Coat weights were measured by difference, as explained in Experimental.
3. The laboratory drawdown unit was used to coat the corresponding uncoated base paper. The viscosity of the coating was adjusted in order to reduce the solids, thereby reducing the coat weight. This procedure was continued until the target coat weight corresponding to a machine coat weight was obtained.
4. The print quality target was printed onto the lab and continuously coated sheets, and also onto the uncoated base paper.
5. Image analysis was performed to define the values discussed under Measures of Color Ink Jet Print Quality.
6. Graphical analysis was done to compare the print quality of the uncoated sheet, the laboratory drawdown sheet, and the continuously coated sheet.
7. The level of agreement or any trends that could provide predictive capability were determined.

Results and Discussion

When preparing continuously coated samples, coat weight control was not very precise. Nor were lab drawdowns able to exactly match the continuously produced coat weights. Table 1 shows the coat weights obtained by the various coaters and the coat weights of the lab drawdowns used to generate comparisons.

Table 1. Continuous Coat Weights vs. Lab Drawdowns

Continuous Coat Method	Continuous Coat Weight (gsm)	Lab Drawdown Coat Weight (gsm)
Puddle	1.30	1.38
Blade	3.12	2.89
Blade	5.61	5.54
MSP	4.09	4.33

Each of the seven measures described in Measures of Color Ink Jet Print Quality was performed on these samples and also on the corresponding uncoated base paper. Examples of measures that had good and poor laboratory predictability of continuous coating are shown in Figure 1 and Figure 2, respectively. (Note: on the graph axes average coat weights are denoted.) Results from each of the seven measures are discussed below.

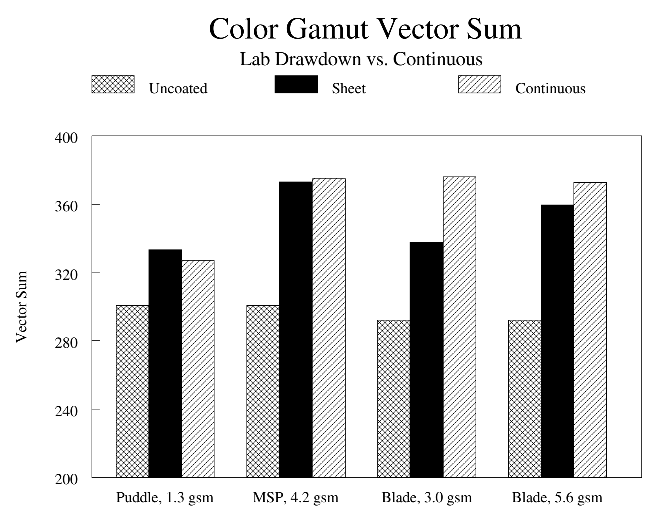

Figure 1: Comparison of the Color Gamut Vector Sum for uncoated, lab drawdown, and continuously coated papers. (Note the non-zero origin.)

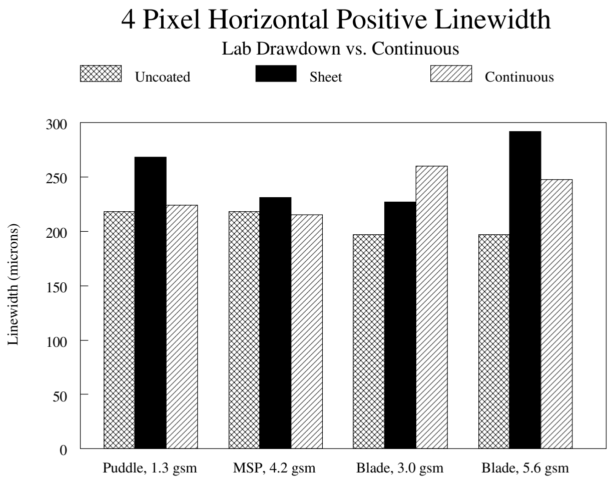

Figure 2: Comparison of the Four Pixel Horizontal Positive Linewidth for uncoated, lab drawdown, and continuously coated papers

Color Gamut Vector Sum:

Data from this case is shown as an example in Figure 1. The data show that in 3 of 4 cases, the laboratory-coated samples accurately predict the continuously coated sample, with the slight exception being a blade coated sample around 3 gsm. As expected, the silica-based coating enhances the color gamut over the uncoated sheet.

Black Optical Density:

In this measure, the lab-coated sheets give black optical densities within a few hundredths of a unit of the continuous sample, indicating excellent predictive ability. However, it should be noted that the range of values for black optical density is limited, ranging only from 1.4 to 1.6. In all cases the silica-based coating gave higher black optical densities over the uncoated sheet.

Print Mottle:

In the case of green mottle, the lab drawdown predicted the puddle press result accurately. The lab drawdown gave reduced mottle to that obtained from the metered size press. In both blade-coated cases, the lab drawdown gave higher mottle than the continuously coated samples. Considering that the mottle can be expected to be an indication of the evenness of the applied coating, rather than a reflection of the components of the coating, it is not unexpected that one application method does not compare well to another.

Bleed:

In the cases of puddle and metered size press, the base sheet had a low bleed, the lab drawdown sheet had negative bleed and the continuous sheet showed positive bleed. In contrast, the base paper used for the blade coater showed high bleed, lab drawdown showed positive or little bleed, with blade coated papers showing high negative bleed. Given these results, the ability to predict bleed from laboratory studies is very limited. Considering the bleed differences between the two uncoated sheets, it is evident that at these low coat weights the base paper is having a large effect on the bleed.

Linewidth:

Data from this case is shown as an example in Figure 2. The data here are scattered and represent a case where predictive ability from the lab drawdown does not exist. In all cases, the lab drawdown results in a higher linewidth than the uncoated base paper. This negative attribute of the coating was not observed when puddle or metered size press application was used, but remained for blade coated papers.

Raggedness:

For raggedness it is found that lab drawdowns consistently overestimate the amount of raggedness. The data also shows that the silica-based coating introduces raggedness over that on the base paper.

Sharpness:

For sharpness the lab drawdown gave excellent predictability in the case of the puddle and the metered size press. The lab drawdown overestimated the sharpness of blade coated papers. In all cases, sharpness was improved over the base papers by the application of the silica-based coating.

Table 2 presents a concise summary of our results.

Table 2. Predictability of Print Quality of Lab Drawdowns Relative to Continuously Applied Coatings

Parameter	Puddle	Blade	MSP	Overall
Color Gamut	E	E	E	E
Black OD	E	E	E	E
Green Mottle	E	O	U	S
Bleed	N	N	N	N
Linewidth	O	E	S	S
Raggedness	O	O	O	O
Sharpness	E	E	O	E

Table Key: E = Excellent Agreement
S = Data Scattered
O = Lab Overestimates Continuous
U = Lab Underestimates Continuous
N = Lab Gives Negative of Continuous

Conclusion

Image analysis-based print quality investigation of a silica-based coating applied using various equipment has yielded interesting results. Laboratory drawdowns were found to be predictive of continuously coated sheets in the print quality measures of color gamut, black optical density, and sharpness. The laboratory drawdowns predicted consistently high values for raggedness and consistently opposite values for bleed. The data for linewidth and green mottle was scattered in a way such that there was limited predictive ability generated by the lab drawdowns in these cases.

Given the complexity and expense of performing commercial trials, the lab drawdown shows enough utility that it can be used as a screening tool for various silica-based ink jet paper coating formulations. Undoubtedly, there is ample room for debate with regards to exactly what print quality measures are most important in judging the comparative performance of various coatings. One approach could be to put the most weight on the parameters that show the most consistent predictive ability.

Print quality benefits of using a silica gel-based coating over an uncoated sheet were clearly observed in measures of color gamut, black optical density, and sharpness. An increase in raggedness was observed on the coated sheets. Mottle and linewidth of coated sheets were largely influenced by the coating method, while the base paper influenced bleed.

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Biography

David Darwin holds a B.A. degree in Chemistry and Integrated Sciences from Northwestern University, a Ph.D. in Physical Chemistry from the University of California at Berkeley, and an MBA from the University of Maryland, College Park. He has worked for W. R. Grace & Co. in Research and Development and in Technical Service Management since 1989. Over those years, his technical programs have been in the areas of cement chemistry, water soluble polymer chemistry, surfactant and colloidal chemistry, formulations, construction materials, and inorganic adsorbents. He is currently conducting research in the area of matte coatings for ink jet papers for Grace Davison, a business unit of W. R. Grace & Co.-Conn.