Color Capability of Inkjet Coating

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Abstract

For inkjet printing, the print substrate plays a vital role in color reproduction. The simplest way to enhance color reproduction capability and print quality of inkjet paper is to add an ink-receptive coating to the paper. A typical inkjet coating formulation includes silica or alumina pigments as the key components, together with a binder and performance enhancing additives. The basic requirement for glossy inkjet paper coating is to fix the anionic inkjet colorants to the coating rapidly and efficiently. Since pigment is the primary determinant of print quality, it is important to understand the benefits and detriments to print quality, when using fumed alumina or fumed silica as coating pigments. The objective of this study is to evaluate the performance of the coatings in terms of roughness, paper gloss, optical density and color gamut. The results confirmed that fumed alumina coatings form smoother and glossier surfaces, while cationic silica has a rougher coating layer. The tested coatings were more attracted to the negatively charged dye-based inkjet ink. For fumed alumina coatings, the addition of polyvinyl pyrrolidone did not expand attainable color gamut. Optical density and color gamut improve with increases in the coat weight, with the exception of some colors printed on the dye-based printer. Additional passes through the calendering nip did not result in a significant improvement in color gamut.

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1. Introduction

Inkjet printing technology is widely used in commercial large format and desktop small format printing for photo, graphic art, and document, as well as a valuable proofing device. The present ink systems used for inkjet printing are water based, containing up to 95% water. In order to absorb ink quickly and produce high-quality color images with inkjet printers, specialty media are required. Inkjet paper employs a surface coating to modify the paper surface structure and properties to provide better inkjet ink receptivity, in order to achieve high print quality and image stability. The design of inkjet coating is for the purpose of providing a number of important properties, such as instant ink absorption, gloss, optical density, wider color gamut, adhesion to the substrate, and defect-free printing to the media. The designed coating determines the mechanism of ink absorption, which in turn governs the ink-drying-time and color fidelity (Lee, et al., 2005; Chen & Burch, 2007; Yoldas, 1998; Chapman & Michos, 2000; Workman & Zhang, 2004).

For photo printing, two coating technologies are currently used: swellable coatings and microporous coatings. Swellable inkjet media typically contain water soluble polymers such as gelatin, polyvinyl alcohol (PVOH), and polyvinyl pyrrolidone (PVP) as binders, a cationic polymer to fix the dye, and a crosslinker to improve water resistance. These systems absorb ink solvents by a film swelling mechanism (diffusion of the ink), which results in slower dry times and risk of ink transfer, smudging, and ink bleed in high humidity environments (Chen & Burch, 2007; Chapman & Michos, 2000). Microporous coatings became the preferred technology for producing high quality instant dry glossy inkjet paper, since to these coatings build up a porous network for the absorption of ink-solvents. As ink droplets hit the surface, capillary action pulls them quickly into the coating. Microporous coatings comprise inorganic oxides such as fumed silica, fumed alumina, colloidal silica, polymer binders such as PVOH and gelatin, and cationic polymers (Chen & Burch, 2007; Chapman & Michos, 2000; Workman & Zhang, 2004).

For the optimum ink absorption and the highest gloss, the highly structured nano-particle pigments, such as a fumed alumina and fumed silica are suitable. These materials provide special pore structures and surfaces ranging from 50–700 m^2/g (Batz-Sohn., Storeck & Scharfe, 2004). When printing the image, this surface serves as a carrier of dyes or pigments. At the same time, the particles form voids and capillaries in the layer due to their unique fractal structure. These voids and capillaries make it possible to absorb the water of the ink droplets within fractions of a second, thereby resulting in instant drying. This instant dry performance of microporous coatings enables the use of high speed printers while achieving optimum image quality.

There are several types of amorphous silica, including fumed, colloidal, precipitated and gel. Fumed silica is the oldest commercial method to produce an amorphous silica pigment. It involves the reaction of silicon metal and gaseous dry hydrochloric acid to form silicon tetrachloride. This mixture is burned at 1000°C to produce and condense a high purity silica pigment (Withiam, 1999). The fumed silica is a very fine particle size product with high levels of microporosity. It is one of the most important inorganic oxides used for the high performance porous inkjet media, due to its high ink absorbing capability, hydrophilicity, and ease of modification (Chen & Burch, 2007; Withiam, 1999; Krupkin et al., 2005).

Alumina is also a popular pigment used in inkjet coating for photorealistic imaging. It is easy to disperse, easy to stabilize in water, provides high absorption capacity, high gloss, and large color gamut, resulting in high quality prints. Alumina particles form intraaggregate pores, because there is space left in between adjacent single primary particles. These pores are needed to provide absorption capacity (Krupkin et al., 2005).

Usually, inkjet inks have negative charge, therefore, it is preferred that the coating layer have a positive charge to fix the ink dye or pigment to the surface (Batz-Sohn., Storeck & Scharfe, 2004; Bugner, 2002). Alumina particles have cationic charge. For silica, a new technique employs a surface modification with special cationic polymers, resulting in a zeta potential curve nearly identical to the curve for alumina. These cationically modified silica nanoparticles are used in glossy topcoats because of their glossing potential and compatibility with cationic additives (Krupkin et al., 2005).

Binders used in coating formulations are responsible for the binding of the pigment particles to the base sheet and the binding of pigment particles to each other. Polyvinyl alcohol (PVOH) is the preferred binder for inkjet coatings, because it ensures a fast set-off, good water resistance of the prints, and provides high brilliance of colors ("CelvolTM Polyvinyl Alcohol," 2007). Polyvinyl pyrrolidone (PVP) is another binder used for inkjet coatings. It is a hygroscopic, amorphous polymer. PVP is soluble in water and other polar solvents. In solution, it has excellent wetting properties and readily forms films. PVP binds to polar molecules very well, because of its polarity. This has led to its application in coatings for photo-quality inkjet papers.

One of important properties for photo quality papers is gloss. Paper gloss is optimized by increasing the refractivity of the coating layer and minimizing the roughness of the coated surface layer. Usually, smooth glossy and white paper produces good distinctness of image, contrast and quality appearance. Optical density is the ability of a print to absorb light. It is an important quality control indicator in the printing process, because it affects the final visual quality, color gamut and color fidelity. Optical density of inkjet papers is determined by colorant concentration and dot coverage (Lee, Joyce & Fleming, 2005).

The color gamut is the range of colors that a particular combination of printer, ink, and print media can achieve. Color gamut of a given printing system is 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. Therefore, color gamut can be treated as an indicator predicting color reproduction capability of a device. Recently, gamut volume with a given printing device has been proposed as a measure of the quality of paper and its coating (Chovancova, et al., 2005; Chovancova-Lovell & Fleming, 2008).

Coated inkjet media are necessary to produce the desired glossy image characteristics and provide good color reproduction capability. Since coating pigment is the primary determinant of print quality, it is important to understand the benefits and detriments to print quality, when using fumed alumina or fumed silica. The objective of this project is to evaluate the performance of the fumed alumina and fumed silica inkjet coatings in terms of roughness, paper gloss, optical density and color gamut.

2. Methodology

Commercial pigment samples of cationic silica (Cabot 022) and fumed alumina (Cabot 003) were used. Celvol 103 fully hydrolyzed polyvinyl alcohol (PVOH) and polyvinyl pyrrolidone (PVP) were used as binders. Formulations were prepared using a 4:1 pigment:binder ratio. Table 1 lists the coating formulations used in this project. Table 2 shows the physical properties of coating formulations. As shown in Table 2, the final solids content of fumed alumina coatings can reach 30%, while the final solids content of cationic silica is only 18%. The addition of PVP in the fumed alumina coating significantly increases viscosity of the coating.

Table 1. *Coating Formulations.*

Coating		FA1	FA2	FS
Pigment	Fumed Alumina	100	100	
	Fumed Silica			100
Binder	PVOH	25	20	25
	PVP	0	5	0
Surfactant	Foamaster	0.2	0.2	0.2

Table 2. *Properties of Coating Formulations.*

Coating	Final Solids content, %	pH	Viscosity, cP (at 100 rpm)
FA1	30.74	4.22	316 (#4 spindle)
FA2	30.55	4.00	810 (#4 spindle)
FS	18.67	9.64	232 (#4 spindle)

The base sheet used in coating experiments was sized paper. Physical properties of the base sheet were basis weight of 81.85 g/m^2, Parker Print Surf roughness of 6.42 μm, TAPPI brightness of 92.04%, and paper gloss (at 75°) of 16.1. Coatings were prepared using various Mayer rods (5–52) and air dried. Three different coat weights were applied: 7 ± 1 g/m^2, 12 ± 1 g/m^2, and 22 ± 1 g/m^2. The coated inkjet papers were calendered on the soft-hot nip calender (60–65°C) through 3 nips before performing any gloss measurements.

Paper gloss was measured at 75° using a Novo-Gloss™ Glossmeter. A Parker Print-Surf (PPS) tester was employed to measure roughness of coated sheets. Samples were then printed on two different printers: an Epson Stylus Pro 4000 printer with UltraChrome pigmented inks and a Canon PIXMA Pro 9000 printer with dye-based inks. Although the UltraChrome ink set in the Epson printer lacks the extended Red and Green inks that are found in the Canon printer, the previous testing showed that both printers can yield very similar gamut sizes on commercially available glossy substrates (Lovell, 2007). It was confirmed in order to continue with the color gamut assessments on investigated glossy coatings. ICC profiles were generated for these coated papers. A 6x8-in. RGB chart was printed on the coated sheets without any ink limitation. Those printed charts were then measured with an X-Rite DTP70 and the ICC profiles were generated by using MonacoProfiler software. The gamut volumes achieved from both printers on the coated papers were derived from ColorThink 3.0 Pro software.

3. Results and Discussion

3.1. Coated Paper Properties

Figure 1 and Figure 2 display roughness and paper gloss properties for each coating, respectively. It is suggested by the data in Figure 1, that fumed alumina coatings (FA1 and FA2) tend to orient and pack together tightly, producing a smoother surface than cationic silica coating (FS). The roughness of the coating increased with increasing coat weight in FA2 and FS, and decreased with increasing coat weight in FA1. Due to low solids content of cationic silica coating (18%), excess coating water penetrated into the base paper, resulting in fiber swelling. The roughness of fumed alumina coatings was in the range of 2.4 to 3.7 µm, while the cationic silica coating had a wider range of roughness, 2.5 to 5.5 µm.

Gloss is a function of surface smoothness. The highest gloss was found in FA1 coating (Figure 2), which is in accordance with its smoothest surface (Figure 1). The gloss of fumed alumina pigments was higher than that of fumed cationic silica pigments. The paper gloss values of FA1 coating are up to 40%, the gloss of FA2 coating is in the range of 35% to 40%, and the FS coating has lower gloss values of 23% to 30%.

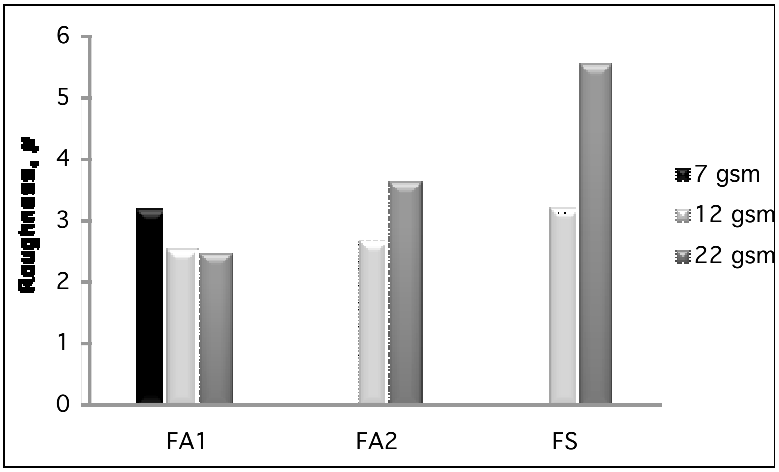

Figure 1. *Roughness as a function of coat weight.*

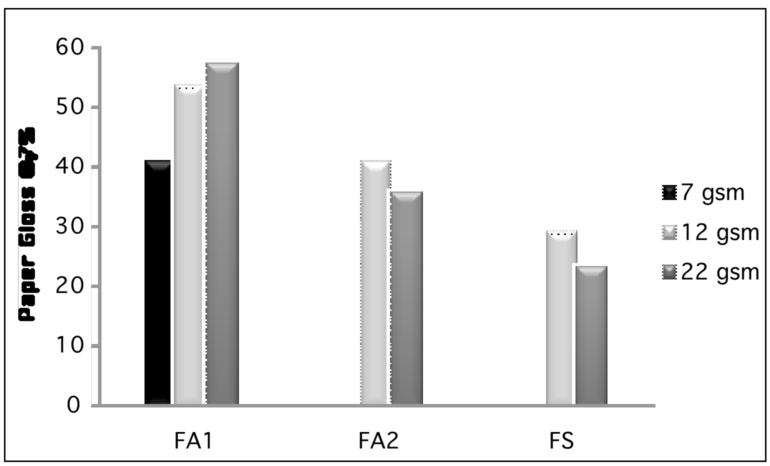

Figure 2. *Paper gloss as a function of coat weight.*

3.2. Optical Density

Optical densities are averaged for the process colors, cyan, magenta, yellow, and black and plotted for the three coatings and two inkjet printers. On average, the tested coatings provided maximum densities when printed with the dye-based inks independently of the coat weight. The positive charge of cationic silica contributes to the dye fixation of dye-based inks.

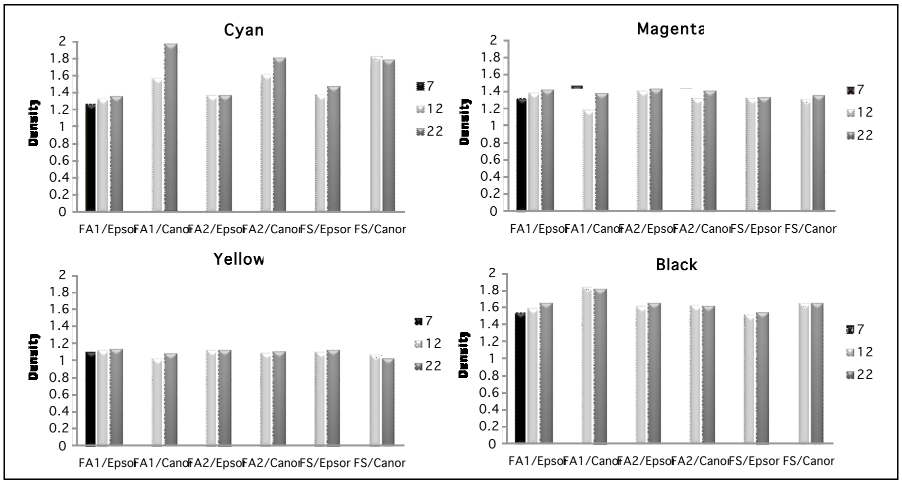

Figure 3. *Optical density due to coating formulation and printer type.*

3.3. Color Gamut

Color gamut comparison for each coating were illustrated in Figure 4. The dye-based printer has better color capability for all formulated coatings, which corresponds to the density measurements presented earlier. Cationic silica coating (FS) did well on the dye-based printer, though less with the pigment-based printer. For fumed alumina coatings, the addition of PVP did not expand the color gamut. Fumed alumina coating (FA1) with PVOH alone has better color capability, which is very apparent in the case of the dye-based inks.

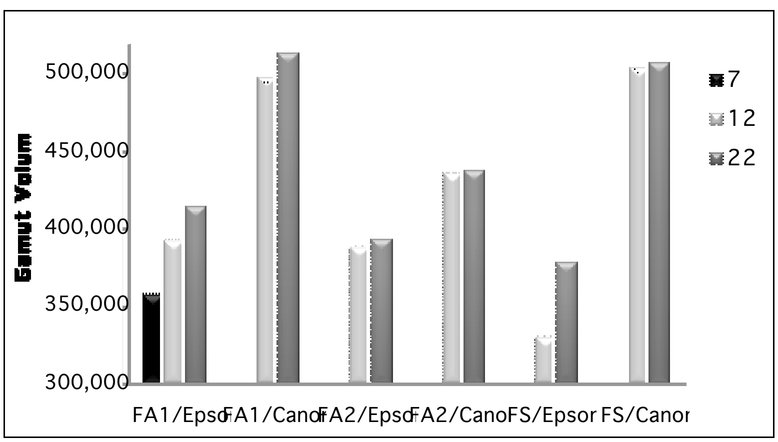

Figure 4. *Gamut volume as a function of coating formulation and printer type.*

3.4. Effect of Coat Weight on Optical Density and Color Gamut

The influence of coating formulation and coat weight on optical density and color gamut are shown in Figure 5 and Figure 6, respectively. Also seen in Figure 3, the density values of fumed alumina coatings increase slightly as coat weight increased when the pigment-based printer was employed. Coated samples printed on dye-based printer did not follow this trend. As shown in Figure 5, both the coat weight and pigment type influenced the optical density. Generally, density increases as the coat weight increased, since increasing the amount of coating materials improves properties of the coated surface. In this study, however, not all coatings followed this trend. When the pigment-based printer was used, the optical density values of fumed alumina coatings increase as coat weight increased. The black density value of cationic silica coating (FS), however, decreased as coat weight increased. When the dye-based printer was used, the density values of coatings decrease as coat weight increased, with the exception of the cyan color.

In Figure 6, the color gamut expands with increasing coat weights except for FA2 coating. The addition of PVP did not expand the color gamut. Conversely, the gamut volume decreases as coat weight increases. Cationic silica coating (FS) has better color capability with the dye-based printer. When printed on the pigment-based printer, however, the FS coating yields a smaller color gamut.

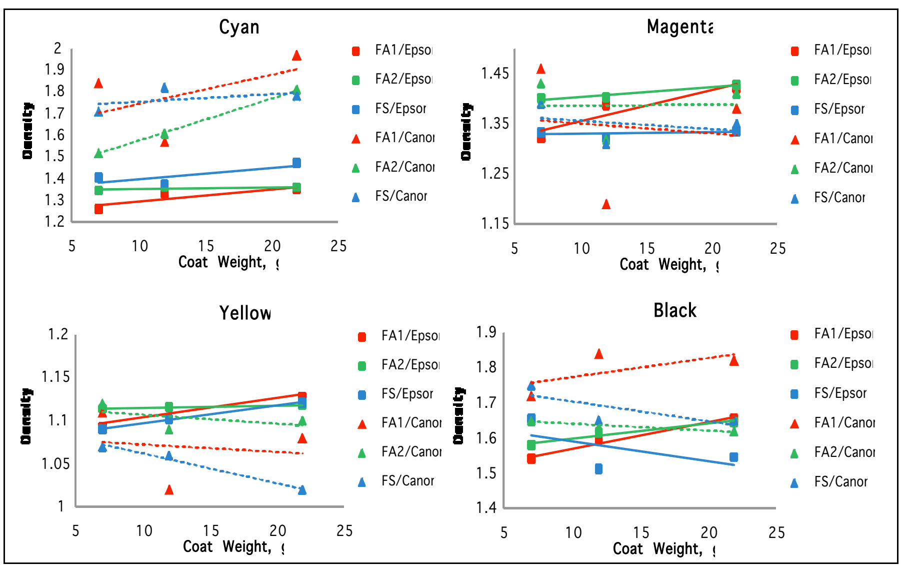

Figure 5. *Effect of coating formulation and coat weight on optical density.*

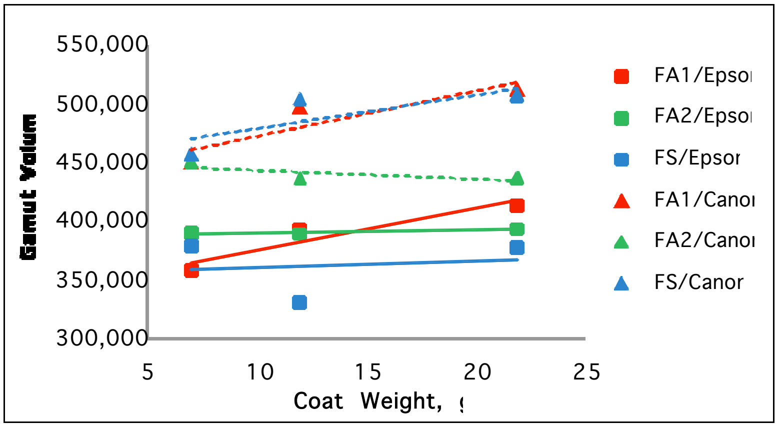

Figure 6. *Effect of coating formulation and coat weight on gamut volume.*

3.5. Effect of Calendering on Optical Density and Color Gamut

Calendering is usually the final step in the production of a coated paper. It has a decisive influence on many end-use properties. Usually, coated papers are calendered to increase gloss and improve smoothness. Figure 7 shows the effect of calendering on surface roughness and paper gloss. As expected, calendered paper has a smoother and glossier surface. The steepest slopes, decreasing roughness and increasing gloss values, are found with the fumed alumina coatings. In order to further investigate the influence of calendering on optical density and color gamut, the coated inkjet papers with coat weight 12 g/m^2 were calendered on the soft-hot nip calender (60–65°C) through 6 nips, providing data to compare with 3 nips condition.

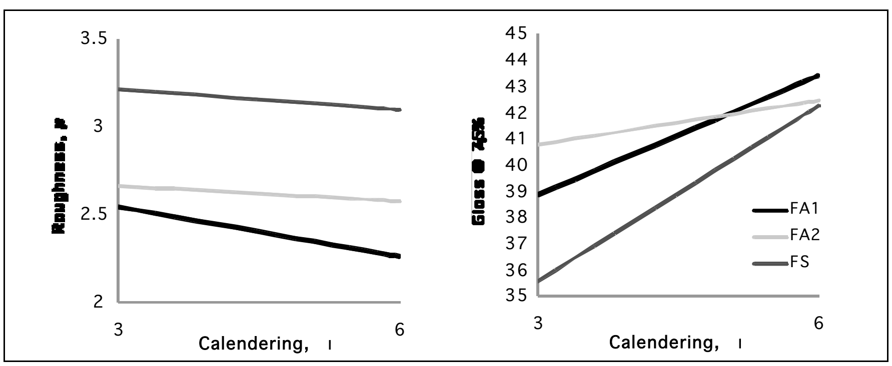

Figure 7. *Effect of calendering on roughness and gloss.*

The effect of calendering on density values was exhibited in Figure 8. Density consequently increased, presumably due to a more closed pore structure of the treated coating surface. However, density values of the tested coatings did not get all of the benefits from the higher degree of calendering. Calendering can cause compression of the coating layer, which in turn affects the ink setting properties. As seen in Figure 8, calendering has less influence on coating samples when printed on the pigment-based printer, most likely due to better holdout ability of pigmented ink on the more open surface. Magenta density values, however, decrease with a higher degree of calendering. Calendering has more impact on coating samples when printed on the dye-based printer. Higher degree of calendering can improve optical density. The degree of calendering has less influence on the FA2 coating, which contained the PVP binder.

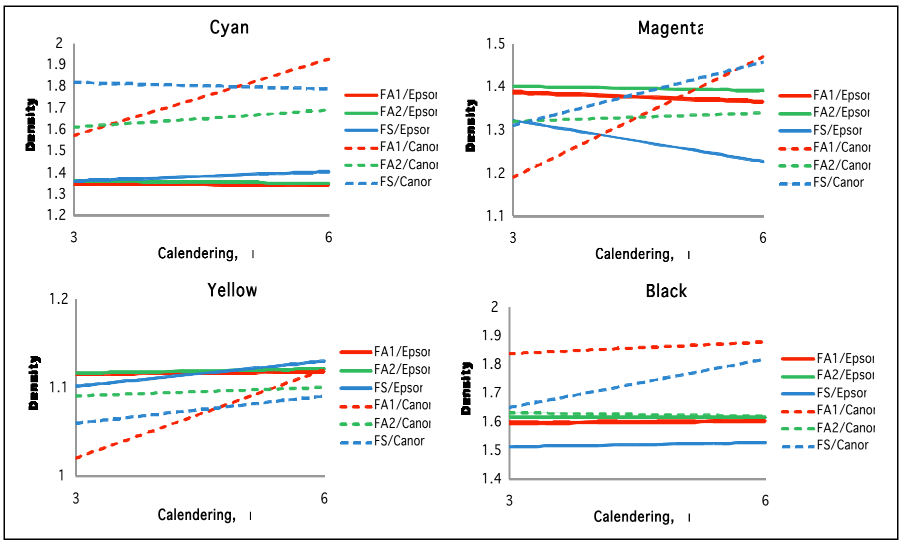

Figure 8. *Effect of calendering on optical density values (coat weight: 12 gsm).*

Figure 9 shows the effect of calendering on gamut volume. The degree of calendering had little effect on the gamut volume of the samples. Gamut volumes of tested coatings tend to increase slightly with higher degree of calendering. The gamut volume of cationic silica coating (FS), however, decreases with a higher degree of calendering.

4. Conclusions

Fumed alumina coatings can reach about 30% solids content. Higher solids content allow pigments to run at higher coat weight. Due to less coating water used in the production, less dryer capability is required. Cationic silica with low solids content (18%) encounters problems with drying and is harder to reach the desired coat weight. Excess coating water penetrates into the base paper and swells fiber, resulting in a rougher surface. Fumed silica coatings are also well known for crack occurrence, most likely because of the low solids content (Lee et al., 2002). Therefore, fumed alumina coatings (FA1 and FA2) produce a smoother and glossier surface than cationic silica coating (FS).

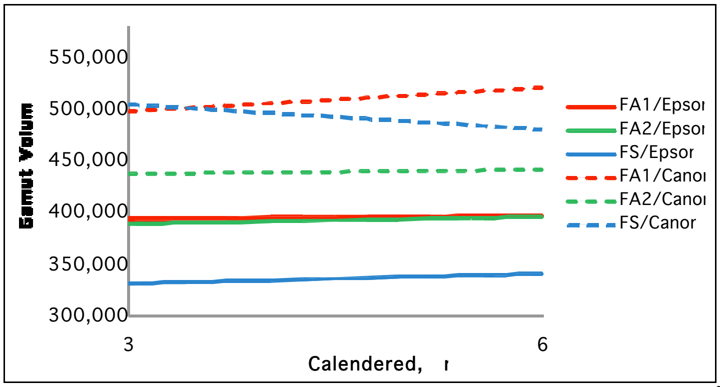

Figure 9. *Effect of calendering on gamut volume (coat weight: 12 g/m^2).*

The dye-based printer has better color capability for tested coatings. Tested coatings were more attracted to the negatively charged dye-based inkjet ink. For fumed alumina coatings, the addition of PVP did not expand the color gamut. Fumed alumina coating (FA1) with PVOH alone has better color capability, especially when the dye-based printer was used.

Generally, optical density and color gamut improve with increases in the coat weight, since increasing the amount of coating materials improves properties of the coated surface. Some exceptions were observed when the dye-based printer was used. The color gamut expanded with increasing coat weights, except for the FA2 coating.

Calendering is widely used to improve the smoothness and gloss of coated papers. Optical density consequently increased with higher degree of calendering. However, calendering can also cause compression of the coating layer, which in turn affects the density for some colors. Excessive calendering is not desirable when it damages the desired absorbency of the coating layer.

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