Hindawi Publishing Corporation
Advances in Materials Science and Engineering
Volume 2016, Article ID 4863024, 10 pages
http://dx.doi.org/10.1155/2016/4863024

Research Article

Effects of Single and Blended Coating Pigments on the Inkjet Image Quality of Dye Sublimation Transfer Printed Paper: SiO_2, $CaCO_3$, Talc, and Sericite

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Received 7 May 2016; Revised 28 July 2016; Accepted 10 August 2016

Academic Editor: Massimiliano Barletta

In this study, we investigated the effects on the image quality of $CaCO_3$, SiO_2, talc, and sericite on coated inkjet paper. The papers serve as dye sublimation transfer paper for printing on fabrics. The brightness, smoothness, and contact angle of the coated papers were evaluated. The papers were then printed with a textile color image evaluation test form, and the imprinted images were evaluated with respect to six criteria of the solid ink density, tone value increase, print contrast, ink trapping, grayness, and hue error. The overall printed image quality was correlated with the smoothness and brightness of the coated paper but showed no correlation with the contact angle. For single-pigment-coated papers, $CaCO_3$ produced paper with the best color difference performance and could be substituted for silica. On the other hand, SiO_2 was found to be suitable for blending with talc, calcium carbonate, and sericite, and its combination with these materials generally produced better image qualities than silica alone. Talc and sericite, when blended with silica as composite coating pigments, produced better printed image qualities than those as single-pigment-coated papers. The overall image quality ranking suggests that the best performance was achieved with $CaCO_3$-, SiO_2/talc-, $CaCO_3$/SiO_2-, SiO_2/sericite-, and SiO_2-coated papers.

1. Introduction

In the 1990s, inkjet printers were introduced to dye sublimation transfer printing, through which a sublimation ink design can be adapted to several standard off-the-shelf desktop units; this allowed the technique to become popular without investing in expensive facilities. Dye sublimation transfer printing is one of the applications of digital printing, which can transfer images printed on color inkjet paper onto several substrates, mainly textiles (T-shirts), ceramics (mugs), glass, plastics (keychains, identification tags, decorative auto license plates, etc.), rubberized polyester (mouse pads, coasters), coated metals, and so forth [1].

In the operation of dye sublimation transfer printing, special sublimation inks in liquid gel ink form are sprayed onto high-release inkjet heat transfer paper through a piezoelectric print head. The inkjet paper is then placed in a heat press to allow contact of the paper with the substrate. Through an endothermic reaction, the special sublimation transfer inks sublime as gases, and the ink is transferred onto the substrate at the molecular level when heated to 194~216°C (typically, the reaction is initiated at 177°C). When ink sublimes, the molecules infuse into the substrate which differs from traditional printing such as screen printing and direct-to-garment printing in which the inks only stay on the surface. Therefore, sublimation transfer printed substrates appear to be nearly permanent and have high resolution and a full-color printing effect. Under normal service conditions, printed images will not crack, fade, or peel from the substrate [1]. There are mainly two types of piezoelectric dye sublimation inks: the mainstream form is a water-based ink used in desktop and large-format printers and the other is solvent

Table 1: Physical properties of the 4 pigments investigated [12, 13].

Item	Silica	GCC, H90	Talc	Sericite
Main ingredients		$CaCO_3$ 98.3%		SiO_2 54% Al_2O_3 31% K_2O 7%
Crystalline structure	Tetragonal	Rhombic	Monoclinic	Monoclinic
External appearance	Platy	Spherical	Platy	Platy
Specific surface area (m^2/g)	>100	14	9~20	57
Hardness (Mohs)	2.2~2.6	3.2~3.5	1.0~1.5	2.2~2.4
Range of particle size (μm)	0.01~0.10	0.1~ 4.0	0.25~5.0	0.8~45.0
Average particle size (μm)	0.09	0.39~0.41	1.2~1.5	10.0~14.0
Specific gravity	3.42	2.67	2.7	2.6~2.7
Refractive index	1.55	1.56	1.57	1.59~1.62
Reflectance (%, at 457 nm)	—	95	97	70
Brightness (% ISO)	85~95	93~96	73~80	65~75
pH	8~11	8.8~9.6	4~5	7~9
Aspect ratio		1	—	30~40
CEC (meq/100 g)		—	−15.7	5.0
PCD (meq/g)		−1.9	72.5	−48.4

GCC: ground calcium carbonate; CEC: cation-exchange capacity; PCD: particle charge detector.

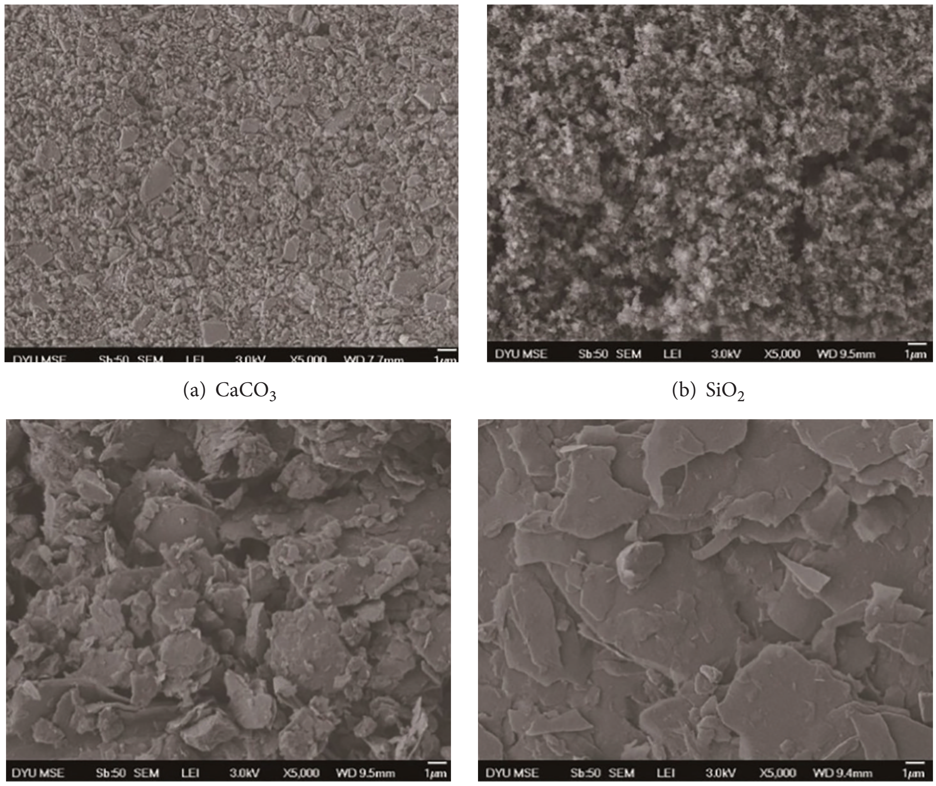
dye sublimation ink which is used in wide-format printers [2].

Yin et al. [3] applied cationic SiO_2/TiO_2 hybrid sol (CSTHS) to coat a cellulosic substrate to improve its surface properties. They investigated using dispersed dyes to inkjet the coated paper and the subsequent heat transfer effect. The experimental results indicated that the transfer rate of the dispersed dyes increased from 21% to 89%. The saturation C^* of inkjet-printed paper sharply increased, and the wet rubbing fastness improved half a grade. The treated cellulosic substrate showed significant improvement in transferred patterns compared to that on an untreated substrate. El-Sayad and El-Sherbiny [4] investigated the effects of coating with clay and ground calcium carbonate (GCC), together with a plastic pigment on the surface structure and mechanical properties of coated papers. Their results indicated that the paper coarseness of coated papers was significantly reduced. Compared to uncoated paper, mechanical properties such as the tensile strength, stretch, tensile energy absorption (TEA), and burst index were significantly enhanced. Incorporating a plastic pigment into coating colors can improve paper properties. When heat is applied to a polyester fabric, the optical density of the coated paper will be slightly higher than that of uncoated paper. When inkjet-printed paper is sublimation transfer printed, the paper incorporating a plastic pigment had a higher optical density than that without it.

The above literature review suggests that there are only a few research reports on dye sublimation transfer printing technology. This study aimed mainly to develop coating formulations suitable for use with high-release inkjet transfer printing paper. The basic property requirements of dye sublimation transfer printing paper are more stringent than those of traditional color inkjet paper. Not only must the rate of ink absorption be rapid, but the holdout also has to be good, as the ink should not penetrate into the fiber substrate of the paper but should be retained on the paper surface or the coated layer. Hence, there must be a substantial degree of pore volume in the coated layer. Also, when placed in a heat press, as much of the inks should be sublimed as possible and be transferred from the paper surface onto the substrate. The inks should not be back-trapped onto the paper surface due to pressure; therefore, the coated layer must have suitable releasing properties. Due to the ink uptake requirement, a typical dye sublimation transfer printing paper has a grammage of 90~140 g/m^2. The higher the paper grammage, the greater its capacity to hold inks; however, in the heat transfer operation, the heat press must also run more slowly.

In this study, using a coating with polyvinyl alcohol (PVOH), four pigments with different morphologies, that is, $CaCO_3$, SiO_2, talc, and sericite, were incorporated. Inkjet printing and heat sublimation transfer printing performances were then evaluated. In this study, the pigment loading was less than the critical pigment volume concentration (CPVC) and differed from conventional inkjet coating formulations. The main objective was to examine how pigments of various morphologies in the PVOH binder performed in heat sublimation transfer printing and thus identify potentially cheap coating formulations for such purposes and to enhance market competitiveness. This report is the first of two papers that deal with inkjet printing performance. In a second paper, the quality of heat sublimation transfer printed images on a textile substrate will be evaluated and discussed.

The basic properties of the four pigments are shown in Table 1. Their scanning electron microscopic (SEM) diagrams are shown in Figure 1. In traditional inkjet paper, silica pigments are often used as the main pigment in the formulation.



(a) $CaCO_3$ (b) SiO_2

(c) Talc (d) Sericite

Figure 1: SEM images of the four pigments (×5000).

Silica has a minute platy appearance, exhibits hydrophobicity, and has an average particle diameter of 9 nm. This gives it a very high specific surface area (>100 m^2/g). A high degree of pore volume and optimal pore size distribution in the coated layer allow rapid penetration of the inks. However, because of the high specific surface area, the solids content of the coating color should not exceed 30%; otherwise, there will be difficulties in coating. In addition, a higher proportion of binder is needed, leading to higher coating color costs [5, 6].

Calcium carbonate and modified calcium carbonate were developed for use in inkjet printing paper to substitute for a portion of silica pigments, enhancing the solids content of the coating color and reducing production costs [5, 7].

Talc is a platy mineral with surface hydrophobicity, an average particle diameter of 1.2~1.5 μm, and a fairly low ion exchange capacity (IEC) of 2.4 meq/100 g. In a coating formulation containing calcium carbonate/clay, talc can be substituted for grade I clay to reduce the low-shear viscosity of the coating color, but at a cost of loss of the water retention value. Coated paper properties with talc can improve printed glass, smoothness, coarseness, IGT (Institute for Graphic Techniques Holland) peeling resistance, ink absorption, dry and wet peeling strengths, and so forth. However, talc tends to reduce gloss and prolong ink drying times [8].

The sericite we used is produced endemically from the east coast of Taiwan. It is a swelling platy mica mineral with average particle size of 10~14 μm and has a fairly high IEC of 5 meq/100 g. One of the developed applications of sericite is as a functional filler to increase first-pass retention and filler retention, improve paper smoothness and sizing degree, and so forth. It has even been found to decrease the use of fluorochemical greaseproof agents [9–11]. When used in coatings, sericite can be substituted for clay; it adjusts the rheological properties and water retention value of the coating color and improves the smoothness, opacity, and barrier properties of the coated paper [12–14].

PVOH provides acceptable binding strength and an adequate coated layer structure to pigments with high specific surface areas. Therefore, most inkjet printing paper uses PVOH as a binder [5, 15].

Thus, this report mainly investigated the effects of four pigment morphologies of $CaCO_3$, SiO_2, talc, and sericite on the image quality of inkjet printing and heat transfer printing. As mentioned above, this paper deals specifically with the inkjet printing performance, whereas a second paper will discuss heat transfer printing results. First, single-pigment effects were examined; we also investigated effects of blends of 50/50 dual pigments (for a total of six combinations) on the image quality. Ten sets of coated paper were examined for their brightness, smoothness, and contact angle properties. The inkjet printing image quality was evaluated using a self-developed textile color printing evaluation test form, which is shown in Figure 2. The form includes (1) a textile pattern zone, (2) a color (cyan, magenta, yellow, and black (CMYK)) gradation wedge, (3) a digital process wedge, (4) a doubling zone, (5) a resolution and registration wedge, and (6) a color

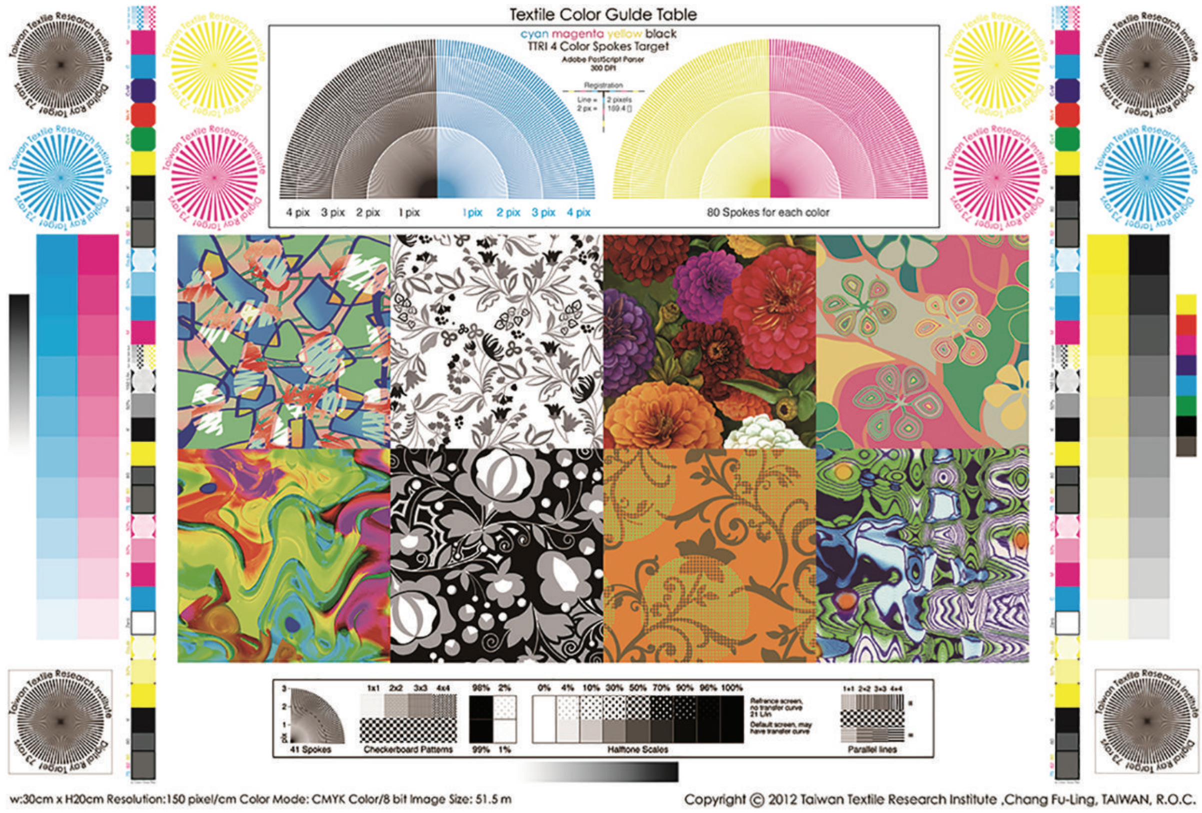


Figure 2: A color printing test form for evaluating textile images [16].

bar [16]. Through the visual information design of the test form, the printed image quality was evaluated using six criteria: the solid ink density (SID), tone value increase (TVI) or dot gain, print contrast (PC), ink trapping, grayness, and hue error or color difference.

2. Experimental

2.1. Experimental Design. In this study, we mainly investigated the effects of incorporating four pigments of $CaCO_3$, SiO_2, talc, and sericite into PVOH binder formulations on the inkjet printing performance (this paper) and heat transfer printed results of dye sublimation transfer paper (a second paper in the series). First, the effects of single pigments were examined; then 50/50 blends of dual pigments (for a total of six combinations) were used in coating formulations. The combinations of coating formulations are shown in Table 2. Each experimental set was repeated ten times to calculate the standard deviation (SD). There were 100 experimental sets in total. The brightness, smoothness, and contact angle with an aqueous liquid of the coated papers were evaluated. Coated papers were then color printed with a test form (Figure 2) using an Epson Stylus Pro 7880 inkjet printer. Six image criteria of the SID, TVI (dot gain), PC, image trapping, grayness values, and hue errors of the printed papers were measured using a densitometer.

The density (D) was defined as $D = \log(1/r)$. Density does not represent color rendering per se, but it is used in the printing industry to describe ink (colorant) transfer onto a printed substrate. In multicolor printing, filters are used to

Table 2: Ten coating formulations of dye sublimation transfer papers.

Coating	Pigment			
	$CaCO_3$ (%)	SiO_2 (%)	Talc (%)	Sericite (%)
Formula 1	100			
Formula 2		100		
Formula 3			100	
Formula 4				100
Formula 5	50	50		
Formula 6	50		50	
Formula 7	50			50
Formula 8		50	50	
Formula 9		50		50
Formula 10			50	50

Note. Binder polyvinyl alcohol dose: 100 parts.

determine the status of colorant transfer. The same applies to the SID, PC, trapping, and dot gain [17].

2.2. Methods

2.2.1. Materials. The base paper was made by Jiutang Mill, Chung Hwa Pulp and Paper (Kaohsiung, Taiwan), and had a grammage of 90 g/m^2, was 250 × 353 mm, and had brightness of 87.9% ISO, opacity of 95%, smoothness of 30.53 s/10 mL, and contact angle (with water) of 69.3°. Calcium carbonate was from Lih Hsiang Omya Co. (Ilan, Taiwan) and was H90 in a slurry with a solids content of 49%. Silica was from Derfu Chemicals (Taichung, Taiwan) and was a white powder. Talc was from Jaw Hwa Mining (Hualien, Taiwan) and was a powder with an average diameter of 6.23 μm. Sericite was from Sunshine Mining (Taitung, Taiwan) and was a powder with average particle diameter of 4.5 μm. PVOH was BP-05 from the Chang Chun Group (Kaohsiung, Taiwan) and consisted of granular particles with a solids content of 98% and alkalinity of 85~90 mg $CaCO_3$/L. The dye sublimation inkjet ink was J-tech dispersive dye from Epson (Taipei, Taiwan).

2.2.2. Facilities and Apparatus. The coating bar was a #0 linear bar (Taiwan). The stirrer was from IKA (Taichung, Taiwan) with a speed of 2000 rpm. The supercalender was model 30FC-200E from Kumagai Riki Kogyo (KRK) (Tokyo, Japan). The brightness meter was model 577 from Photovolt (Minneapolis, MN, USA). The smoothness tester was number 168 from Toyoseiki (Tokyo, Japan). The contact angle goniometer was model 100SB from Sindatek Instruments (Taipei, Taiwan). The dye sublimation transfer printing paper sender was an Epson Stylus Pro 7880 mainframe unit (Suwa, Nagano, Japan). The reflective optical densitometer was an X-Rite® SpectroEye Spectrophotometer (Grand Rapids, Michigan, USA).

2.2.3. Procedures. For the coating operation, a pigment slurry at a 15% solids content was stirred at 3000 rpm for 30 min. PVOH was added → #0 linear coating bar (coat weight controlled to 1.9~3.2 g/m^2) → coated paper (oven drying at 105°C) → supercalender (300 psi, room temperature single pass).

For color inkjet printing, coated paper was printed using an Epson Stylus Pro 7880 mainframe unit. Inkjet printing conditions were 720 dpi unidirection, with 8 print heads; dithering with smart diffusion; a resolution of 720 dpi; density adjustment with Epson 7880-720 dpi.Dns; the printer profile was an Epson 7880.icm; and the total ink limit was 300%. Dispersive dyes were together with color RIP software by TexPrint RIP version 14 (ErgoSoft AG).

The measurement operation used an X-Rite SpectroEye Spectrophotometer reflective densitometer. Specialized calibration of the digital inkjet printing output facilities for textiles used a GMG® Print Control and Rapid Check unit and an X-Rite Measure Tool to establish color descriptive files and for the density value analysis. Color temperatures were designated as Spectrum CIELAB 6500 K, with an observer angle of 10° and density designation of status E. When measuring densities, a white sheet was used for calibration; thus, differences in the reflectance of coated papers did not affect the measurements.

3. Results and Discussion

3.1. Properties of the Coated Papers

3.1.1. Brightness. Effects of coating formulations on the resulting coated paper brightness are shown in Figure 3. As

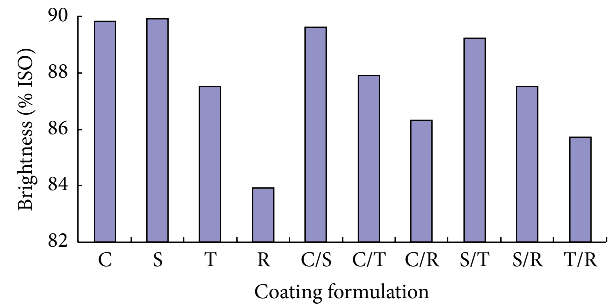


Figure 3: Effects of coating formulations on the brightness of coated papers, C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, at mixing ratios of 50/50.

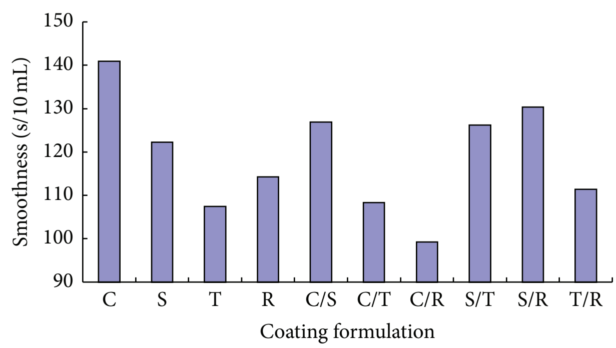


Figure 4: Effects of coating formulations on the smoothness of the resulting coated papers, C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

influenced by the intrinsic brightness of the pigments, for single-pigment-coated papers, the brightness ranking was SiO_2 ≒ $CaCO_3$ > talc > sericite. Dual combinations showed similar trends, with brightness rankings of $CaCO_3/SiO_2$ > SiO_2/talc > $CaCO_3$/talc > SiO_2/sericite > talc/sericite.

3.1.2. Smoothness. Effects of coating formulations on the smoothness of the resulting coated papers are shown in Figure 4. Smoothness is an indicator of the evenness or bumpiness of the paper or board surface and is critical for printing papers, as it influences the first-pass ink transfer onto the paper surface. The higher the smoothness of the paper is, the more even the paper surface becomes. Figure 4 shows that, after a single pass in a supercalender, the single-pigment $CaCO_3$ set with spherical particles produced the highest smoothness, followed by the SiO_2 set with minute particle sizes and then sericite, with the talc set lagging behind. Among dual-pigment combinations, the smoothness ranking followed the order of SiO_2/sericite > $CaCO_3/SiO_2$ ≒ SiO_2/talc > talc/sericite ≒ $CaCO_3$/talc, and the paper with the worst smoothness was the $CaCO_3$/sericite set.

3.1.3. Contact Angles. Effects of coating formulations on the contact angles of the resulting coated papers are shown in Figure 5. The contact angle manifests the surface tension in the solid-liquid interface, and the higher the degree, the greater the surface tension. Results indicated that, among

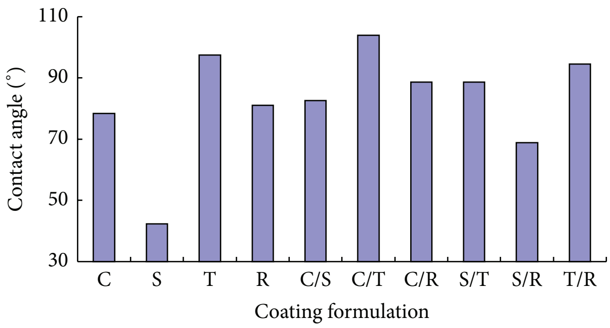


Figure 5: Effects of coating formulations on contact angles of the resulting coated papers, C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

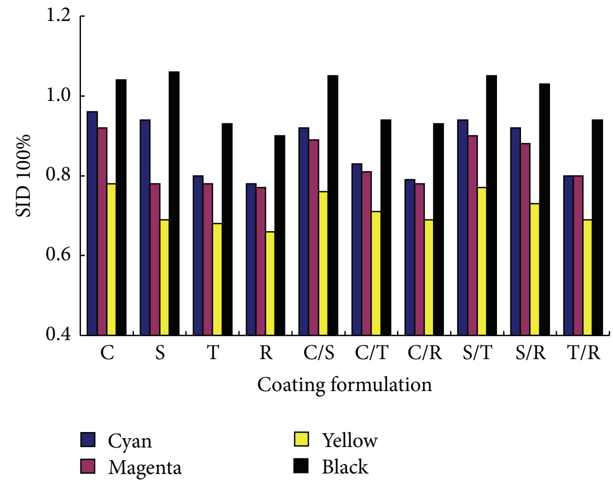


Figure 6: Effects of coating formulations on the cyan, magenta, yellow, and black (CMYK) solid ink densities of inkjet-printed papers, C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

single-pigment sets, platy talc had the highest contact angle, followed by sericite, $CaCO_3$, and SiO_2 with the least contact angle. Among dual-pigment sets, blending with talc effectively improved the contact angle of the talc/SiO_2 set. Among the dual-pigment sets, the contact angles from high to low were in the order of $CaCO_3$/talc > talc/sericite > $CaCO_3$/sericite ≒ SiO_2/talc > $CaCO_3$/SiO_2 > SiO_2/sericite.

3.2. Color Inkjet Printing Performance of Test Papers

3.2.1. SID (Solid Ink Density). The SID refers to optical density values when the dot coverage of the printed paper is 100%, in other words, when the coated paper is totally covered by ink. Density values are the most important factor affecting the color effect. SID values determine concentrations of the inkjet spray, the tone value increase, and the repeatability of printed color tones. Density values directly indicate the amount of light reflected and hence can be used to judge the color intensity and thickness of the ink of the printing. In general, the higher the density values are, the more intense the CMYK appears; and the greater the color range, the better the efficacy [18].

The coating formulation of a coated paper exerts influences on the SIDs of CMYK, and results are shown in Figure 6. In the figure, one can see that, for cyan inkjets, the $CaCO_3$, SiO_2, $CaCO_3$/SiO_2, SiO_2/talc, and SiO_2/sericite sets performed better; for magenta inkjets, the $CaCO_3$, $CaCO_3$/SiO_2, SiO_2/talc, and SiO_2/sericite sets performed better; for yellow inkjets, the $CaCO_3$, $CaCO_3$/SiO_2, and SiO_2/talc sets did better; and for black inkjets, $CaCO_3$, SiO_2, $CaCO_3$/SiO_2, SiO_2/talc, and SiO_2/sericite sets had better performances. The four groups with the highest brightness were, respectively, the $CaCO_3$, SiO_2, $CaCO_3$/SiO_2, and SiO_2/talc sets. This trend was similar to the SID performances of the C, M, Y, and K inkjets. The phenomena indicated that SIDs had positive correlations with the brightness of the coated papers.

Overall, for single-pigment-coated papers, $CaCO_3$ had the best C + M + Y + K printed SID color performance, whereas, for dual-pigment sets, the SID of SiO_2/talc was the best, followed by the SiO_2/$CaCO_3$ and SiO_2/sericite sets. From these results, it was deemed that silica, with its fine grain diameters and large specific surface areas, is capable of providing a higher light scattering coefficient and thus is suitable as a dual-pigment coating color ingredient for making inkjet printing papers. Overall SID effects suggested that dual-pigment sets performed better than single-pigment sets, with the ranking of $CaCO_3$ > SiO_2/talc > $CaCO_3$/SiO_2 > SiO_2/sericite > SiO_2 > $CaCO_3$/talc > talc/sericite > talc ≒ $CaCO_3$/sericite > sericite. The SID experimental results showed a similar trend with paper smoothness in Figure 4. However, due to the exceptionally low contact angle of SiO_2, the contact angle data provided no discernible correlation with SID. This was probably due to the low pigment loading which was less than the critical pigment volume concentration (CPVC); therefore, pigments took up less volume, and the contact angles did not show an appreciable effect on inkjet printing.

3.2.2. Tone Value Increases (TVIs or Dot Gains) at 30%, 50%, and 70% Dot Coverage Extents. Effects of coating formulations on TVIs at 30%, 50%, and 70% for CMYK are shown in three separate graphs in Figure 7. Tone value increases are the differences in dot coverage between certain portions of a printed item compared to dot coverage of a corresponding portion on the original. The TVI exerts critical influences on volume printing effects. Due to the factors of press pressure, printing speed, and so forth, TVIs are unavoidable, whereas the value must be controlled to an acceptable level. Controlling the TVI is thus an important factor in assuring printing effects. In principle, the TVI should be as small as possible; however, for general printed items, the standard of the trade generally recommends 10% ~ 25% for 50% dot coverage. According to specifications of ISO 12647-2 paper type 1, printed items shall have TVIs of +3%, +4%, and +3% for dot coverage extents of 30%, 50%, and 70%, respectively.

From Figure 7, at a TVI of 30%, except for the Y inkjet which remained within the allowable limit, other inkjets of

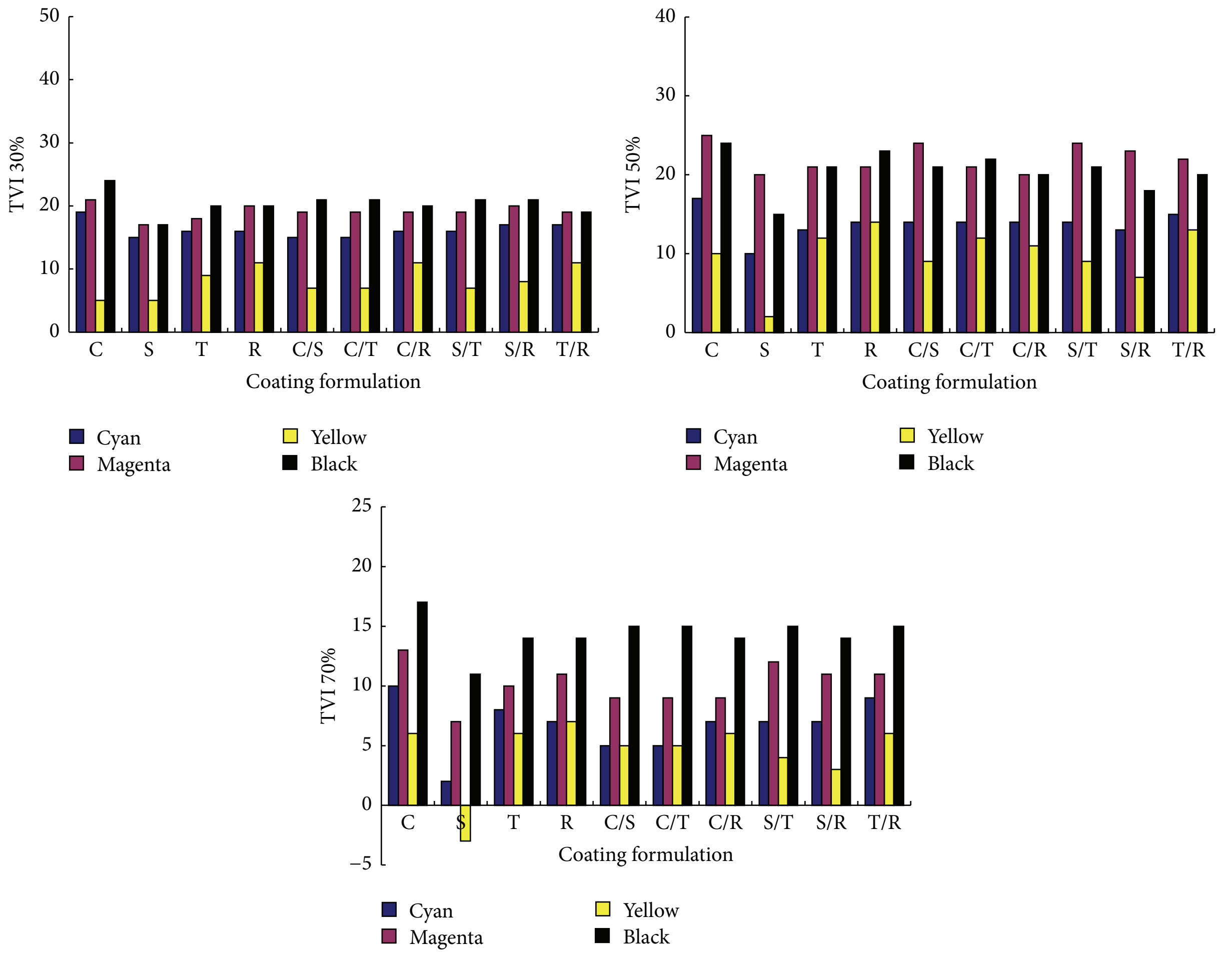


Figure 7: Effects of coating formulations on tone value increases (TVIs) of cyan, magenta, yellow, and black (CMYK) at 30%, 50%, and 70% dot coverage. C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

C, M, and K all showed TVIs. For TVIs of 50% and 70%, all dot gain values were within acceptable limits. For single-pigment-coated papers, the $CaCO_3$ set had maximum dot gains for the C, M, Y, and K inkjets; for the SiO_2 set, Y inkjets with a TVI of 70% measured a strange −3% value, while the set had the best TVIs for C, M, Y, and K of all coating formulations. Overall, except for the $CaCO_3$ and SiO_2 sets, both dual- and single-pigment-coated sets showed very small percentage differences among the C, M, Y, and K inkjets. These observations might be related to the $CaCO_3$ set having higher brightness and lower yellowish tint. Therefore, paper coated with it had the highest dot gains for the C, M, Y, and K inkjets. The SiO_2 set had similar brightness; therefore, except for the Y inkjet, all other inkjets had good dot gains.

3.2.3. Print Contrasts (PCs). Effects of coating formulations on the PCs of the CMYK inkjets are shown in Figure 8. The PC is an important indicator for judging whether darker tones have sufficient steps. The higher the PC, the richer the tone steps in the darker tones. PC values are influenced by the SID and brightness of the coated paper. Calculation of PC uses a comparison of the tones of SID to three quarter-tone steps [18]. The equation is as follows:

$$\text{Print contrast (PC)} = \frac{(D_s - D_t)}{D_s} \times 100\%, \quad (1)$$

where D_s is the tone of the SID (including the optical density of paper) and D_t is the tone densities of three quarter-tone steps (including the optical density of the paper).

Figure 8 indicates that, for cyan inkjets, the SiO_2 set had the highest PC, followed in order by $CaCO_3/SiO_2$, SiO_2/talc, and SiO_2/sericite; for magenta inkjets, the SiO_2 and $CaCO_3/SiO_2$ sets were also in the lead, followed by SiO_2/sericite; for yellow inkjets, SiO_2 again had the best PC, followed by SiO_2/talc, SiO_2/sericite, and $CaCO_3/SiO_2$; and for black inkjets, SiO_2 was also in the lead, followed by SiO_2/sericite. Thus, among single-pigment-coated papers, SiO_2 had the best PC performance, whereas dual-pigment-coated papers generally outperformed other single-pigment-coated papers, particularly when SiO_2 was blended with $CaCO_3$, sericite, or talc. The SiO_2 set showed better PC; this might have been due to silica having fine grain diameters and large specific surface areas. When it was mixed with other pigments, a higher light scattering coefficient was conferred as well. Although the $CaCO_3$ set also had high brightness,

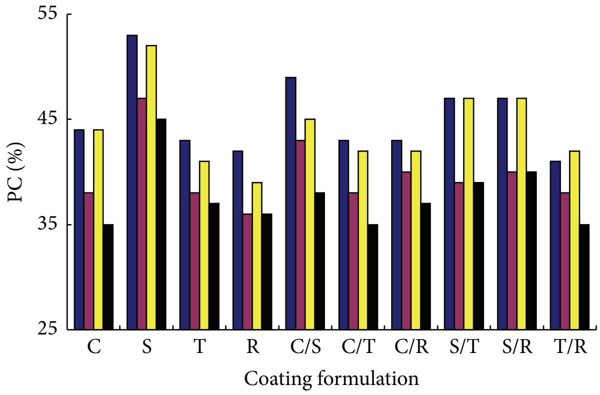


FIGURE 8: Effects of coating formulations on the print contrasts (PCs) of color inkjet-printed papers. C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

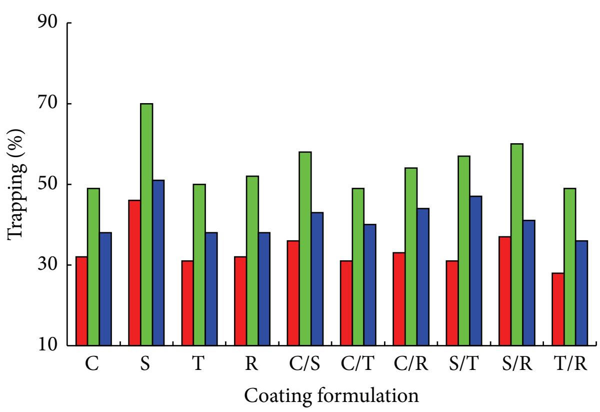


FIGURE 9: Effects of coating formulations on red, green, and blue (RGB) plate image trapping of color inkjet-printed paper. C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

because of its coarser grains, when mixed with other pigments, no synergistic effect was apparent, and therefore it did not affect the PC to the same extent.

3.2.4. Image Trapping. Effects of coating formulations on image trapping when color inkjets separately printed red, green, and blue (RGB) are shown in Figure 9. Image trapping represents the ability of a second ink to transfer onto a previous ink film. Image trapping values approaching 100% mean that the ability is good. After the second ink is uniformly printed onto the previous ink film, image trapping and opacity can be examined. Image trapping at <100% represents a condition of undertrapping, meaning that less ink was transferred onto the previous ink film than that onto a blank sheet of paper. Image trapping of >100% is called overtrapping [18].

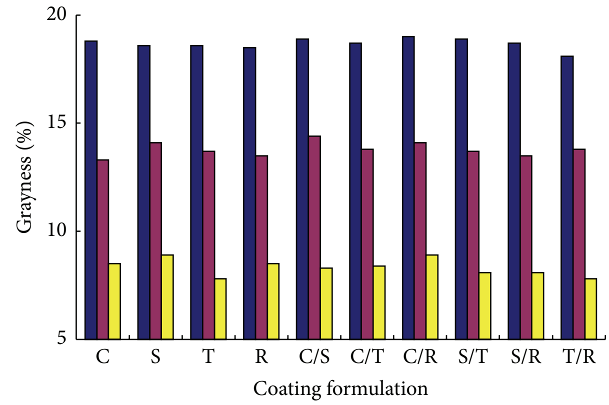


FIGURE 10: Effects of coating formulations on grayness values of color inkjet-printed papers. C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

From Figure 9, it appears that, for all experimental sets, image trapping was <100%, indicating insufficient ink transfer. Among single-pigment-coated papers, the SiO_2 set showed better trapping for the R, G, and B inkjets. For dual-pigment sets, the SiO_2/sericite set performed the best in image trapping, followed by $SiO_2/CaCO_3$ and SiO_2/talc. Thus, dual-pigment coatings containing silica resulted in high image trapping values. This phenomenon also explains why the SiO_2 set outperformed all other coating formulations in terms of image trapping values of the R, G, and B inkjets.

3.2.5. Grayness Values. Effects of coating formulations on grayness values of cyan, magenta, and yellow inkjets are shown in Figure 10. The grayness value is an indicator for examining the purity of the inks. If an ink contains minute amounts of the other two tones, grayness will result, which is measured as the grayness value. The degree of grayness will limit the ability of ink dyes to clearly replicate secondary colors. Thus, the lower the grayness value, the higher the tone purity of the ink [18].

From Figure 10, one can see that, for cyan inkjets, the $CaCO_3$, SiO_2, $CaCO_3/SiO_2$, SiO_2/talc, and SiO_2/sericite sets had lower grayness values; for magenta inkjets, the SiO_2, $CaCO_3$, and $CaCO_3/SiO_2$ sets had lower grayness values. All other experimental sets showed high grayness values. However, in general, the yellow inkjets had good low-grayness values, particularly in the $CaCO_3/SiO_2$ set. Overall, except for the good performance of the yellow inkjets, all other coated formulations performed poorly in both the cyan and the magenta inkjets. The above experimental results indicated that grayness values were positively correlated with the coated paper brightness. The coated papers with the highest brightness values were the $CaCO_3$, SiO_2, $CaCO_3/SiO_2$, and SiO_2/talc sets. The trend was similar to the grayness performances of the C, M, and Y inkjets.

3.2.6. Hue Errors. Effects of coating formulations on CMY hue errors of the color inkjet-printed papers are shown in

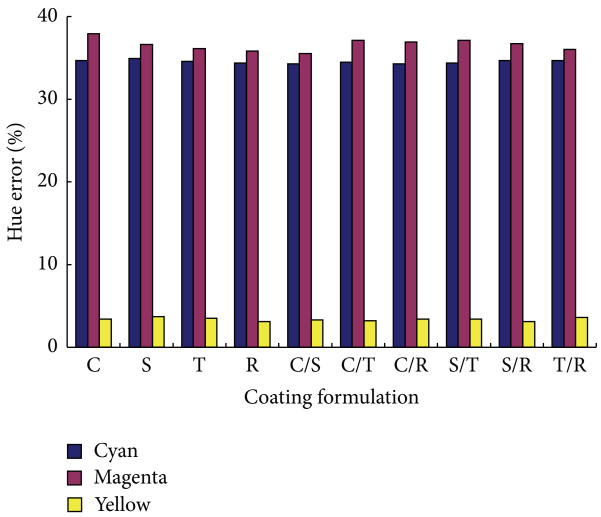


Figure 11: Effects of coating formulations on cyan, magenta, and yellow (CMY) hue errors of color inkjet-printed papers. C: $CaCO_3$; S: SiO_2; T: talc; R: sericite, with mixing ratios of 50/50.

Figure 11. Hue errors relate to the total amount or hue changes as specific hue blends with other hues. In other words, they pertain to the degree of hue variations of a specific hue. The greater the hue error is which a colorant contains, the more difficult it is to precisely replicate a good color from it [18]. As a basis of judging the purity of printing inks, the lower the hue error, the purer the ink.

From Figure 11, one can see that the hue error percentages of the cyan and magenta inkjets were high, with single- and dual-pigment-coated papers having similar performances. Overall, the yellow inkjets showed minor hue errors. Among all sets, the single-pigment $CaCO_3$ set and dual-pigment SiO_2/sericite set performed better with respect to hue errors.

4. Conclusions

This study opted to use pigments of different morphologies to prepare coated papers and examined the subsequent color inkjet printing performances in a bid to develop coating formulations suitable for making dye sublimation transfer printing paper. Summarizing the experimental results, we found that the overall printing effects were correlated with the smoothness and brightness of the coated papers but showed no correlation with the contact angles of the surfaces. Among single-pigment-coated papers, the $CaCO_3$ set showed the best color rendering capability and can be substituted for the more-expensive silica. Silica, on the other hand, is imminently suitable to blend with talc, calcium carbonate, and sericite in equal parts as dual-pigment coating formulations which generally render better printing performances than single-pigment silica-coated paper. The platy talc and sericite, when blended with silica, produced coated paper with printing performances much improved over the single-pigment talc or sericite alone. Overall, the highest ranking coated papers were the $CaCO_3$, SiO_2/talc, $CaCO_3$/SiO_2, SiO_2/sericite, and SiO_2 sets.

It is also noteworthy that our highest ranking coated papers favorably compared with some international commercial brands of dye sublimation transfer printing papers in terms of image quality, indicating that our trial may lead to useful applications. In a second paper, we shall present the results of heat transfer printed image quality on textiles.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

The authors are much obliged to Mr. Shi-ben Chang of the Deep Blue Technologies Co., Taiwan, for providing the measuring facilities and applicative software for determining the properties of inkjet-printed images.

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