Analysis of Inkjet Paper Print Quality: Filling the "Quality Gap"

Frank Huskey
Engelhard Corporation
Gordon, Georgia

Abstract

The print performance of four commercial inkjet papers was documented on thermal and piezo inkjet printers. Papers tested were an uncoated bond, a surface-sized paper, and two matte coated sheets, one with a kaolin-based coating and the other with a silica-based coating. Color density was evaluated with a hand-held densitometer, and dots and lines were analyzed with an imageXpert® scanner-based system.

In general, the results showed kaolin- and silica-based coating formulations had comparable color density and line and dot quality. Both were better than bond and surface treated papers. The silica-based and kaolin-based formulations also worked well with the aqueous inks used in thermal printers. With the solvent-based inks used in piezo printers, a partially hydrolyzed binder in the kaolin-based coating, (as opposed to a fully hydrolyzed binder) gave optimum printability. This formulation gave high-quality results in both thermal and piezo print platforms.

A value analysis of the papers in the study using the line and dot data showed that bond and surface-sized paper were lowest in price and performance, and the kaolin-based coating produced print results close to those of the silica-based pigment but at a much lower cost.

Introduction

Most paper used in industrial and home inkjet printers is commodity bond priced at $0.005 to $0.01 per sheet. This is changing, however, as many computer owners want to improve print results and color reproduction, especially for photographs and high-resolution graphics.

The simplest way to enhance print quality, color density and snap is to add an ink-receptive coating to the paper. The coating performs several essential functions: It keeps the ink on the surface, which increases optical density. It controls ink droplet penetration and spread to reduce wicking, featuring and bleed. And it speeds drying by absorbing most of the vehicle that carries the dye or pigment particles in inkjet printing inks, minimizing cockle and curl.

Coated sheets range from those with surface sizing costing about $0.02 per sheet, to high-quality matte paper at about $0.08 per sheet, to high-end, glossy paper used for photo-realistic output that can cost $0.50 to $1.00 per sheet. The inkjet papers available form a cost-performance "quality pyramid" in which cost and coating quality increase together (Fig. 1).

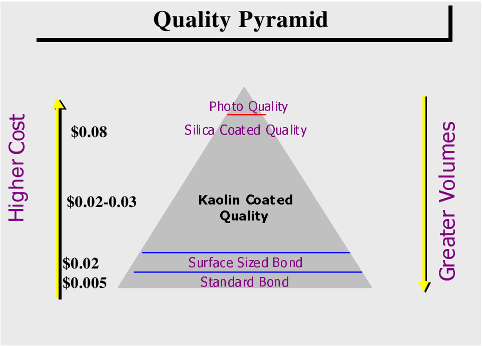

Figure 1

Until recently, was a gap in the middle of this pyramid between surface-sized paper and the premium, matte coated inkjet papers that fall just below glossy photo-quality paper. This gap has been filled by enhanced kaolin-based pigments that improve printing results at a cost close to that of surface-sized paper.

Coated inkjet paper clearly has better printability than bond paper, but which coating has the best performance at the lowest cost? This question was answered by evaluating color density and line and dot quality for different printers using four types of papers -- plain bond, a surface-sized sheet, and sheets coated with silica and surface-enhanced kaolin formulations. Line and dot data were then used to define quality values for each type paper used in the study.

Matte Coatings, Inks and Inkjet Methods

Until recently, most matte coated-inkjet papers silica-based formulations were applied off machine at relatively low speeds, because of their poor rheology and great affinity for water. As a result, they are coated by expensive, off-machine methods.

The need for an economical, matte inkjet paper that can be coated on-machine has been met with DIGITEX™ surface-enhanced, kaolin-based pigment. This pigment can be used on-machine to create a coated paper having comparable print quality to that of silica-based sheets at a price slightly higher than that of surface-sized paper. Commercial and pilot results show this pigment can create high-performing, matte inkjet paper on machine retailing at $0.02 to $0.03 per sheet.

Inkjet inks for thermal and piezo printers are strikingly different. Those for thermal print engines contain deionized water as a vehicle, isopropyl alcohol or glycol as humectants, anionic dyes for color, and a range of proprietary components. Ingredients vary depending on page speed, print head design and color capabilities. While these inks produce excellent results, they lack water resistance.

The pigmented inks used in piezo printers create color with small particles suspended in an organic vehicle. The particles are coated with a polymer that forms a static charge to prevent clumping and settling. These inks are virtually waterproof once they set up on the media. They create sharp images, even on low-grade paper, because they have small particles and are less susceptible to bleed and wicking than dye-based inks. Black pigmented inks, however, tend to have a faded, charcoal appearance, while color pigmented inks do not have as good a color range as dye-based formulations. Pigmented inks also cost two to four times more to make than dye-based inks.

Whatever ink is used in a printer, the final product is ink on paper. In thermal inkjet technology, ink is heated to create a bubble, which bursts under pressure and sends the ink droplet onto the paper. The collapse of the bubble creates a vacuum that draws ink from the reservoir. In piezo technology, piezo crystals flex as an electric current flows through them, forcing drops of ink out of a nozzle.

Optical Color Density

One measure of a paper's printability lies in the color densities of solid CYMK blocks printed on it. This was done for the four papers in the study using a hand-held densitometer with a polarizing filter. The kaolin-coated paper and more expensive silica-coated paper printed by a thermal engine with aqueous-based inks were close in quality (Fig. 2).

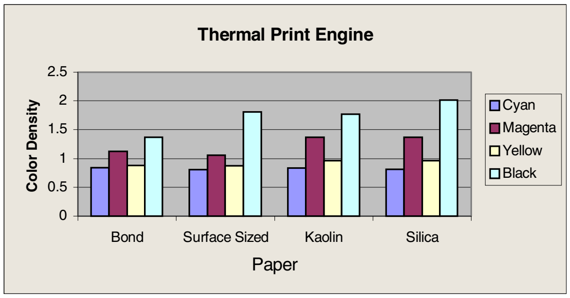

Figure 2

Both matte papers had coating that appeared to be optimized for thermal inks but not for solvent-based piezo inks. To compensate for this, paper with a second kaolin-based formulation having a different binder was added to the piezo portion of the study. One kaolin-based paper had a fully hydrolyzed, polyvinyl alcohol binder (Kaolin I), while the another had a partially hydrolyzed binder (Kaolin II). The binder in Kaolin II has acetate groups that take up excess solvent, whereas the binder in Kaolin I does not. Kaolin I was used in both the thermal and piezo printers.

The piezo results showed that both kaolin- and silica-based coatings had higher color densities than the bond and surface-sized papers (Fig. 3) The silica-based coating has the best performance with this print engine.

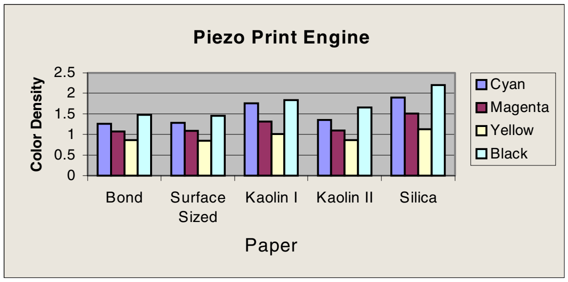

Figure 3

Line Measurement

Line and dot measurements using image analyzing hardware and software from imageXpert Inc. indicated the printability of the four paper types on thermal and piezo printers. Printability measures how well a paper prints on a specific printer using one or more test targets. All variables other than the media were constant, e.g., printer, print driver and imaging system settings.

The line-quality assessment evaluated line width, edge sharpness and line raggedness for the vertical and horizontal lines of a black crosshair on a yellow-block background (Fig. 4).

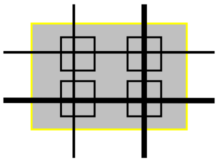

Figure 4

Line width is the average of edge point pairs across the lines in specific regions of interest (ROI) on the target. The smaller the width the better, because line width is greater in blurred images and indicates wicking and feathering. Edge sharpness, or normal edge profile, is the spatial transition from a light to a dark area. Line raggedness, or tangential edge profile, measures how much actual line edge points deviate from the best-fit line through the edge points.

A composite of the three line values measured showed that bond and surface-sized paper were comparable for the thermal print engine (Fig. 5).

This occurred because both papers allow ink to wick along paper fibers. Paper using silica-based and kaolin-based formulations were better than (lower values are better) the other two because the coating controls migration of ink into and along the paper. In this study, the kaolin-based coating gave somewhat better results than the silica-based coating.

Composite line data for the piezo print engine showed that the bond, surface-sized and Kaolin I papers were comparable (Fig. 6). The silica-based paper was significantly better than these three, but not as good as the Kaolin II paper that contained partially hydrolyzed binder.

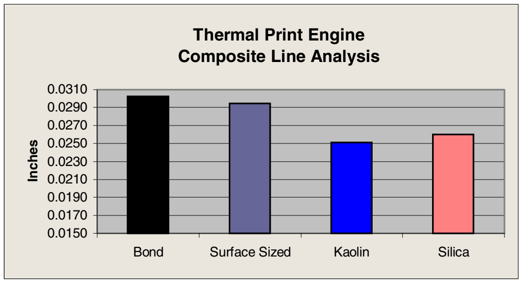

Figure 5

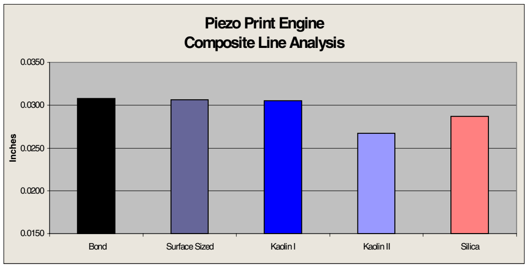

Figure 6

Dot Analysis

Dot quality is affected by the printer, ink and media. Poor dot placement, formation or density creates grainy or mottled images. Dot-related data were compiled by repeated scans through an area of positive black dots (Figure 7).

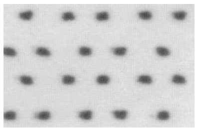

Figure 7

Statistical analysis of the dot population, rather than of a single dot, gave values for dot darkness, size and shape. In this study, the media was the only variable. Dot alignment and satellite formation due to overspray were considered as constant for each print engine.

Gray average is the average gray value of all pixels in the ROI (the area of dots) based on a threshold-dependent binary algorithm. The threshold ranged from zero (black) to 255 (white), so a lower value indicates more uniform ink coverage. Data from the thermal print engine data found that bond gave the worst results. The other papers had comparable gray averages, with silica slightly better than the others (Fig. 8).

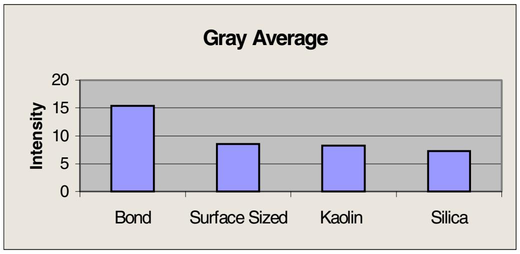

Figure 8

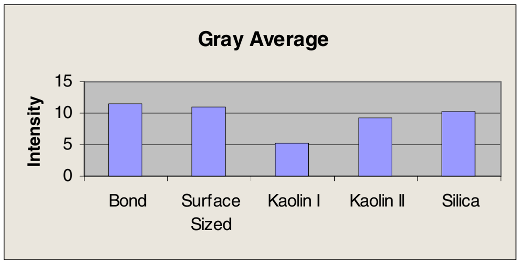

Figure 9

The piezo data found that the Kaolin I formulation had the best gray average by far (Fig. 9).

Area coverage counts the number of pixels within the ROI having gray values above or below the threshold. The data was converted from pixels to square millimeters by calibrating the scanner so that 600 pixels equals one square millimeter. Lower values indicate less wicking or feathering. Area coverage is calculated from:

$$\text{Area coverage} = th/(th+1) + th \tag{1}$$

Where th, or threshold value, is the area of dark pixels and (th +1) is the area of the light pixels.

In the thermal engine test, the kaolin-based formulation had somewhat better area coverage than the silica-based and surface-treated papers (Fig. 10).

In the piezo tests, the silica-based formulation was somewhat better than the other papers used, but the overall differences between them was slight (Fig. 11).

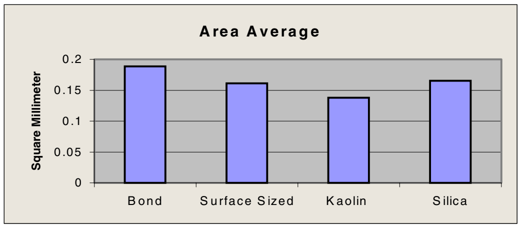

Figure 10

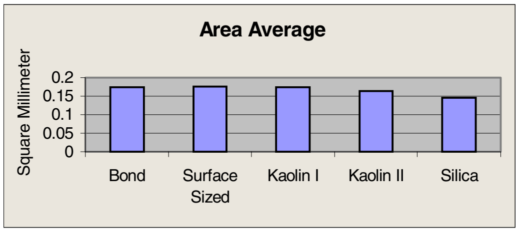

Figure 11

Roundness indicates dot edge smoothness and shape. The roundness of a circle is taken as 1.0, so the closer to 1.0, the more compact the dot and the better the image. The instrument measured the area (A) and perimeter (P) of a large population of dots and calculated roundness from the formula:

$$Roundness = 4\pi A/P^2 \tag{2}$$

The kaolin-based and silica-based formulations gave similar roundness results in the thermal printer (Fig. 12).

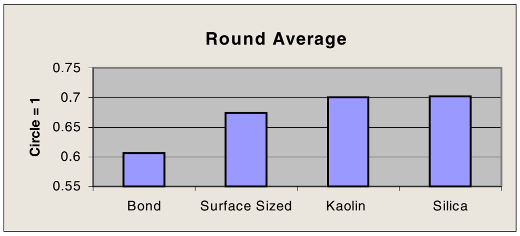

Figure 12

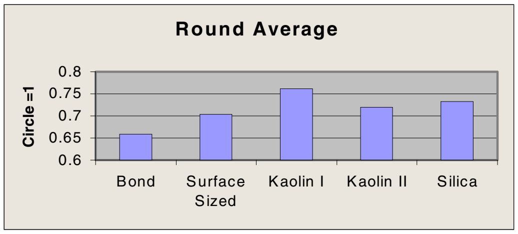

Figure 13

Both were much better than the bond paper and somewhat better than the surface-sized paper, indicating that they allowed less wicking. In the piezo printer, Kaolin I had significantly better roundness than the other papers (Fig. 13). The silica-based sheet was next in line, and the bond paper had the worst roundness.

Table I. L.A.R.G.E Image Quality Value Equation

Image Quality Value Equation for Bond (Thermal)

Line= 1/Horizontal + Vertical Line= 1/.0283=35.5

Area =1/.1888=5.296 *10= 52.95

Roundness = $10^{(\text{IA acquired value})}$ $10^{0.6061} \Rightarrow 4.037 * 10 = 40.37$

Gray =1/15.427=$10^{0.0648}$ = 1.160 *10=11.60

Sum L+A+R+G= **IQV**

Image Quality Value =140.4

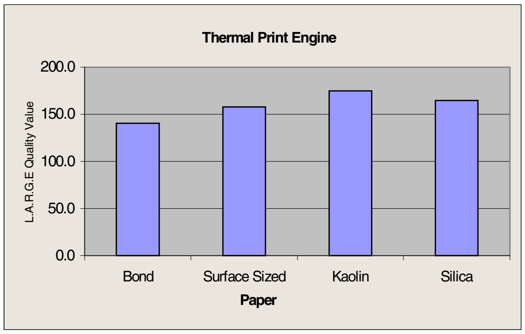

Figure 14

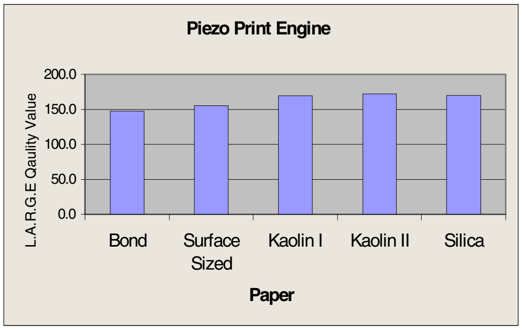

Figure 15

The Quality Pyramid

An algorithm developed by Engelhard was used to calculate inkjet sheet quality from the image analysis results. The quality value is the sum of the composite line value and those for dot area, gray value and roundness. In order to weight all measurements equally, the inverse was taken on line, dot area and gray area value, while dot roundness was taken at 10X, where X is roundness. Table 1 shows a sample quality value calculation.

Quality values based on the image analysis on the thermal and piezo printers (Fig. 14 and 15) showed that the kaolin-based and silica-based formulations gave better quality results than the bond and surface-sized papers. The kaolin-based coating had a slightly higher value than the silica-based coating on the thermal printer. On the piezo printer, the two kaolin-based formulations and the silica-based formulation had comparable quality values.

The quality values calculated from the image analysis were correlated with cost to form a quality pyramid. The quality results obtained (Table 2) verify the paper hierarchy described by M. Londo[1] in which quality and cost increase in the progression from bond, to surface sized, to matte paper with a kaolin-based coating, to matte paper with a silica-based coating, to glossy, photograde paper.

Table II L.A.R.G.E Image Quality Value Comparison

Image Quality Value Comparison Gap Filled

Sample	Thermal	Δ	Piezo	Δ
Bond	140.4	0	147.7	0
Surface Treated	158.0	17.6	155.6	7.9
Kaolin I	174.5	34.1	169.4	21.7
Kaolin II	------	------	172.3	24.9
Silica	164.6	24.2	170.1	22.4

Conclusion

Images printed on inkjet paper by thermal or piezo print engines may be acceptable to the eye, but image analysis (of dots and lines) shows that print qualities vary with print engine and type of paper. When plain bond, a surface-sized sheet and sheets coated with silica-based and kaolin-based coating were printed on these two engines, quantitative image analysis showed that:

- Kaolin- and silica-based coating formulations generally produce comparable color density, line and dot printing results in thermal and piezo inkjet printers. Since matte sheets with the kaolin-based formulation are made on machine, these are significantly less costly than the silica-based sheet and, therefore, provide greater value.
- Both matte sheets gave better color density, line and dot results than bond and surface treated papers.
- Both silica- and kaolin-based formulations work well with the aqueous inks used in thermal printers to prevent wicking and feathering.
- The nature of the binder in the coating formulation affects paper performance on piezo printers. A partially hydrolyzed binder can improve performance because it provides sites that pick up the solvent before it enters the paper. This allows for coating formulations that can work equally well across thermal and piezo print platforms.

In addition, quality calculations confirm that the papers in the study fall into a logical quality price and performance ranking. Bond was lowest in price and performance, and surface-treated paper was somewhat better. Paper coated with an enhanced kaolin-based coating fits between surface-treated and premium matte sheets coated with a silica-based formulation, because the kaolin-coated sheet has a price close to that of surface-treated paper but gives printing results approaching that of the more costly silica-coated sheet.

Acknowledgements

My thanks to Mike Londo, Staff Scientist at Engelhard Corporation, and Kate Johnson, Senior Imaging Scientist at imageXpert Inc, for their help developing and interpreting the data in this study.

References

1. Michael G. Londo, "Surface Enhanced Aluminosilicates as an Alternative to Synthetic Silicas in Inkjet Receptor Coatings," IS&T's NIP 16, 2000 International Conference on digital Printing Technologies, Vancouver, B.C.

Biography

Frank Huskey has a BS in Biology from Georgia College and State University. He has worked in the kaolin industry for the last fourteen years and has spent the past two years in product development. His main project is pigmented ink jet coatings.