Future Color Technologies for Digital Commercial and Industrial Print

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Abstract:

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Future Color Technologies for Digital Commercial and Industrial Print

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Abstract

Future color technologies for digital commercial and industrial print are reviewed in summary form. Then a database of 434 print substrates is introduced and used to empirically analyze current distributions in the color, tactile, gloss and fluorescence properties of these substrates. This data is also used as the context for identifying future technology trends. Substrates with a significant degree of coloration are not unusual although there is a distinctly bi-modal distribution of the hues of media. The tactile and gloss properties also vary widely and in combination with fluorescence present significant challenges for proofing, cross-media reproduction and in-line or near-line quality control of prints. There are also new digital technologies for the direct modulation or control of these properties. Finally the need to simply better organize and communicate all of these features and attributes of print is considered from standpoint of tabular visualization, in this case a 'periodic table' of substrates.

Introduction

Print service providers who have moved into digital printing have generally been quite profitable. According to one source[1], 23% of jobs produced by industry profit leaders were produced digitally, compared to 4.7% for profit laggards. Many trends in print production are favoring short run production, which, in turn, is generally favorable to digital presses. For example, in packaging and labeling we see trends toward private labels, secondary language packaging, and product serialization, all of which require shorter runs and/or variable data printing. Long runs allowed craft to be part of print production. These shorter run jobs can no longer afford the per-job color overhead of craftsmanship and automated workflows are required. Further, many of the shorter run jobs that have moved to digital are the "low-hanging fruit" four process color jobs. Moving forward, digital production will need to develop additional color and surface finish reproduction capabilities to compete for more sophisticated color jobs. Processes that use these new capabilities must be automated to be cost effective. In this paper, we will discuss some of those upcoming digital production color challenges and examine various solutions.

While some digital press manufacturers do offer the capability to print with spot, >4 process colors, and wide gamut inks, they are rarely used in practice. One reason is the cumbersome (and costly) processes of specifying, mixing, loading and calibrating, and maintaining the color consistency of spot and special color inks. Clearly, presses will need to develop embedded, colorimetric closed loop feedback systems to characterize and stabilize these inks. However, "color" measurement will need to move beyond basic 45/0 colorimetry. For example, in order to move into areas such as high end marketing collateral and packaging, the digital application of metallic inks and gloss treatments will be developed. In turn, measurement systems must be developed to mix, and calibrate and maintain such inks and treatments on-press. We must move from color to surface measurement. Goniometric and possibly BRDF (Bi-directional Reflectance Distribution Function) measurement data will be required. Inter-instrument agreement between press-embedded measurement systems and between press-embedded and press-external measurement is essential. Color management systems must support the specification and use of this augmented color and surface data. Smart CMMs will be required in order to incorporate both color and surface information, as well as to deal with the likely dynamic nature of applying surface treatments. Since finishing equipment is likely to apply some of this "color", equipment and associated standards such as JDF and PrintTalk may need to support color data and measurement. Additionally, brand owners are becoming more and more interested in interacting with their customers through printed marks such as barcodes and mobile response codes. Increasingly, color will be used in such codes. Tighter control of color will enable higher information densities.

Due to their short run and time-critical nature, job color approval must be based on softcopy for most digital jobs. Gloss and metallic treatments can be best proofed using color-accurate 3-D renderings of completed finished products. Softcopy approval systems must also support the same goniometric data, rendering color accurate 3-D renderings that can be manipulated by end users. The problem of making an emissive surface appear similar to a reflective surface (i.e. softcopy to hardcopy matching) must be solved, possibly through the use of through-aperture viewing of softcopy.

Print Substrate Database

One approach for exploring the specific considerations raised in the introduction and making some extrapolations to future trends is through an empirical analysis of a large selection of currently available print substrates. The following sections use a measurement database of 434 different print substrates or media to both visualize current color, tactile and other properties and to identify interesting technology directions. These 434 substrates were selected from the broadest possible range of vendors, technologies and applications. There are samples from ink-jet, dry electro-photography, liquid electro-photography and other print technologies. The database includes media for labels and packaging, for office printing and specialty commercial applications. This database provides a starting point for additional measurement and analysis that will be covered in summary form in the final section of the paper.

Color Properties

Even before printing, commercial substrates differ with respect to their color properties. To visualize these properties the CIELAB measurements of print substrates are shown plotted as sorted bar charts. The spectral measurements were made using an X-rite eye-one spectrophotometer. Illuminant E was used as the white point for the CIELAB calculations although the choice of alternative white points will not substantially change the basic conclusions. Figure one shows the sorted L* or lightness values for these media. Note that the x-axis is simply an identification number that is used to represent the media. In this way this axis is, strictly speaking a nominal scale but the density and scale of the data allow this bar chart to provide a visualization of trends and tendencies in the data. In this case it is clear that there is a plateau in this data such that a majority of the substrates have a lightness level in the middle to upper 90's/ In spite of this plateau, there is roughly a quarter of the media with lightness levels below 90. This figure suggest a bi-modal distribution in which a majority of the media are of high lightness but wider range of substrates can have lightness values as low as 50 L*.

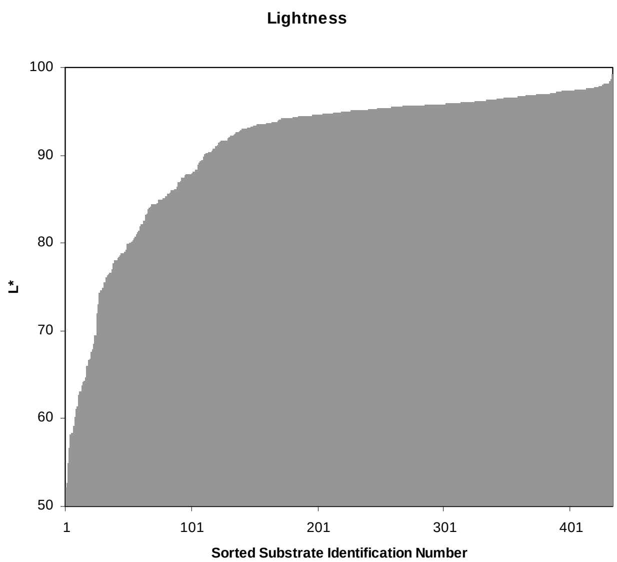

Figure 1. Sorted lightness values for the print substrate database.

The results for the C*ab or CIELAB chroma measurements are shown in Figure 2. The measurement and chart formatting used are similar to those used for Figure 1. The results are however are roughly the inverse of those shown in Figure 1. A majority of the substrates have a chroma value of less than 10. Roughly one quarter of the substrates have higher chroma values, ranging from 10 to over 60 C*ab. The results for the sorted hue as computed with CIELAB is shown in Figure 3. This data clearly shows a strongly bi-modal distribution with one cluster of substrates with hues angles near to 90 degrees while a second cluster of substrates is near the 290 degree hue angle. This roughly corresponds to majority of yellowish and bluish substrates and relatively fewer reddish and greenish media. The results shown in Figures 1 through 3 are for just the substrates, without any printing or imaging. This demonstrates that substrates themselves have a gamut and varying degrees and types of clustering. For commercial print this range of color variation will stress near-line or in-line color measurement systems and will require careful definition of the rendering of colors across media and for substrates with lower lightnesses, higher chromas and less frequent hues.

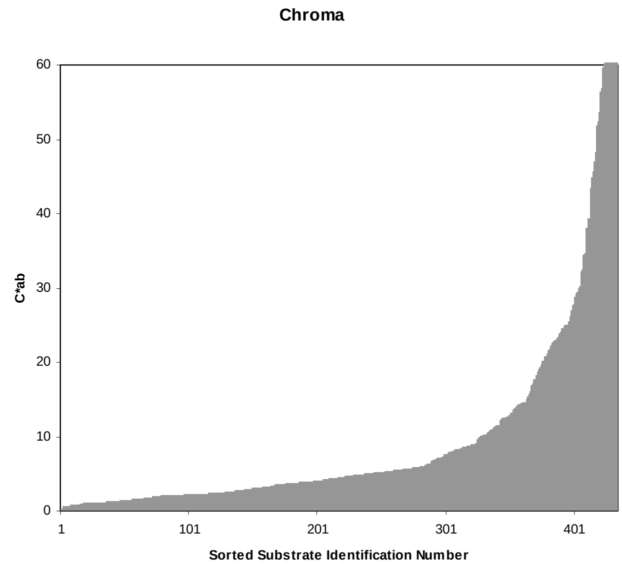

Figure 2. Sorted chroma values for the print substrate database.

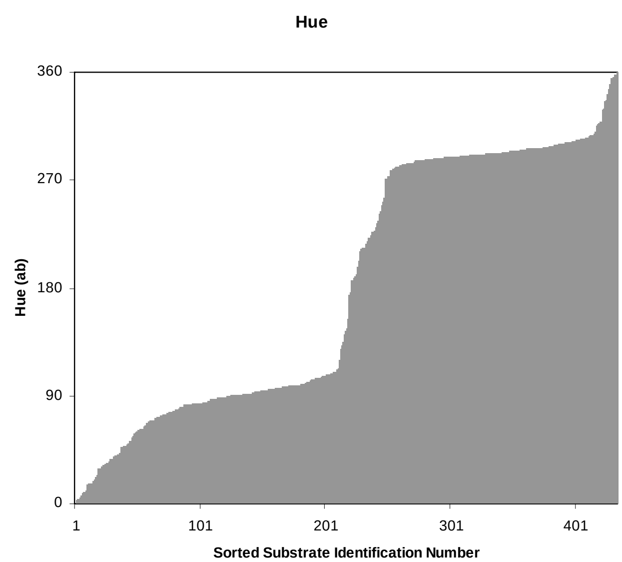

Figure 3. Sorted hue values for the print substrate database.

Tactile Properties

Printed pages vary considerably in their surface topography and thickness. While the corresponding properties of roughness and flex may be closely related to the tactile experience of print, they are also related to the properties of visual texture and opacity.

Therefore it is interesting to consider the measurement distributions of a large number of print substrates. Figure 4 shows a sorted bar chart visualization of surface topography as measured with a TIME TR200 Roughness Tester.. Qualitatively it is interesting to consider the wide range of surface topographies for these substrates. There is no single plateau or obvious central tendency for this data. In addition the upper range of distribution goes up quite high for media with a high degree of tactile and visual roughness.

The sorted thicknesses of substrates are shown in Figure 5. In this figure the data is the thickness as measured using Mitutoyo digital calipers and is in millimeters. This data shows some quantization due to the precision of the calipers. Overall though there is a modest plateau in the data around a thickness of 0.1 mm. There is also a shoulder to the left showing a relative lack of thinner substrates. Above the 0.1 mm plateau there is a gradual increase in thicknesses going up to 0.5 mm. The roughness and thickness results shown in Figures 4 and 5 are not independent of the color properties. For example the rougher media can have evident surface textures, such as canvas or stippling that impact both the visual appearance of the substrate and the tactile experience of the print. Likewise for the thickness distribution it is not uncommon for thinner substrates to have lower opacity and the larger potential for color differences resulting from duplex printing. Future proofing and measurement systems will require a closer understanding of the rendering and quantification of texture and thickness.

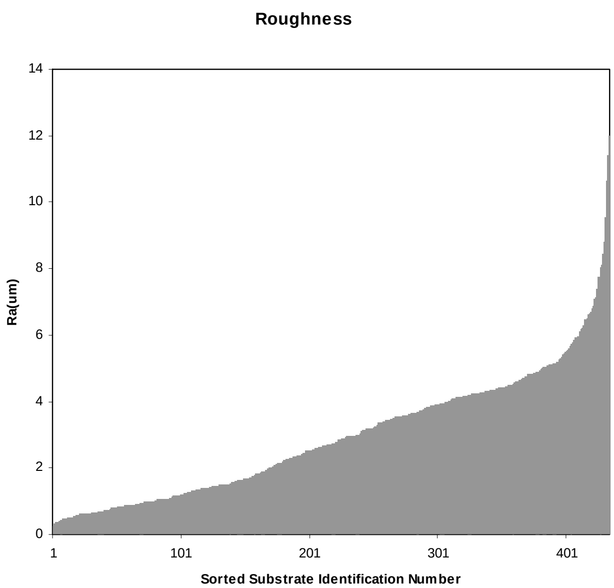

Figure 4. Sorted roughness measurements for the print substrate database.

There are also technologies for the digital modulation of thickness and roughness. Uses of varnishes and lamination are familiar for finishing of printed pages but recently there have been advances reported on the direct digital embossing of pages with thicknesses up to 0.07 mm.[2] These technologies also can be configured to vary the gloss properties. In this way digital production will be able to control a wide range of optical and physical properties of printed surfaces directly.

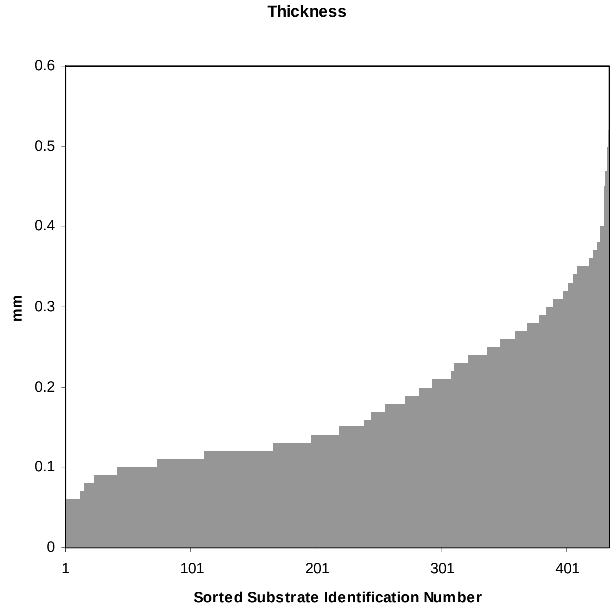

Figure 5. Sorted thickness measurements for the print substrate database.

Additional Properties

Finally the gloss and fluorescence properties will be considered. The gloss was measured with a BYK micro-TRI-gloss meter. This device returns gloss measurements at 20, 60 and 85 degrees. The reference black opal that is included with the gloss-meter is used to calibrate the device to gloss readings of 100, 100 and 100 for this sample. Figure 6 shows the sorted gloss readings at 20, 60 and 85 degrees for the substrates. This figure shows that a majority of the media have fairly low gloss readings at 20 degrees, shown as a region with solid black fill. This may seem at first glance like a significant lack of diversity in media gloss levels. However as the gloss levels at the other two angles show this is not necessarily the case. Figure6 also show the gloss readings at 60 and 85 degrees. The gloss readings at 60 degrees are shown as region with a medium gray while the gloss readings at 85 degrees are shown as a region with a light gray.

The resulting gloss measurements show that while roughly three-quarters of the substrates measurement have relatively low gloss readings at any of the three angles one-fourth of the substrates have a wide range of gloss levels, ranging from 20 up to 100 gloss units. These gloss readings, like the surface texture and thickness, also are inter-related with the color properties. This presents further challenges to the measurement and proofing process. Further, the control of the rasterized application of gloss treatments, such as HP's Digital Matte,[3] will require specification and control of gloss. This differential gloss treatment or spot gloss process is also featured in other digital presses, such as those using clear toners.[4] One important item to note in figures 6 is that while there is a rough correlation between the different gloss readings at different angles, that there is a significant spread in the gloss readings at different angles. This is especially true for comparisons of the 60 and 85 degree measurements. For example there are substrates with gloss readings of roughly 80 at 60 degrees whose gloss at 85 degrees can vary from a low of 20 to a high of 80 gloss units. A plot of the gloss at 60 degrees versus the gloss at 85 degrees is shown in Figure 7. While low gloss readings are consistent at either angle there is a significant spread in the data at higher gloss levels. If there was a close agreement between these angles, the data would tend to fall along a straight line or for a non-linear relationship on a monotonically increasing function or curve. This variation demonstrates the clear need for multi-angle measurements.

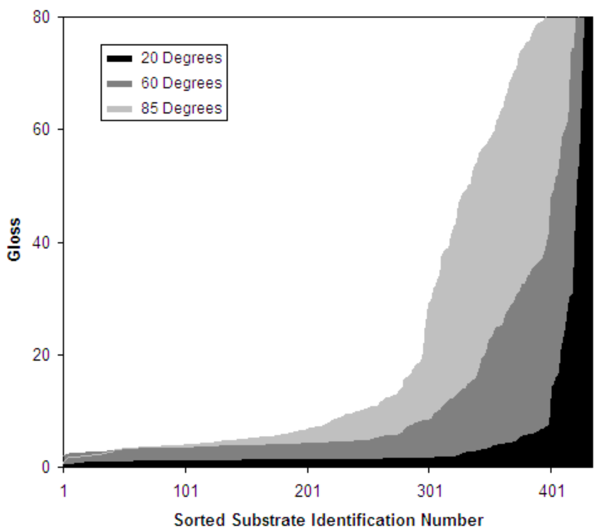

Figure 6. Sorted gloss measurements at 20, 60 and 85 degrees for the print substrate database.

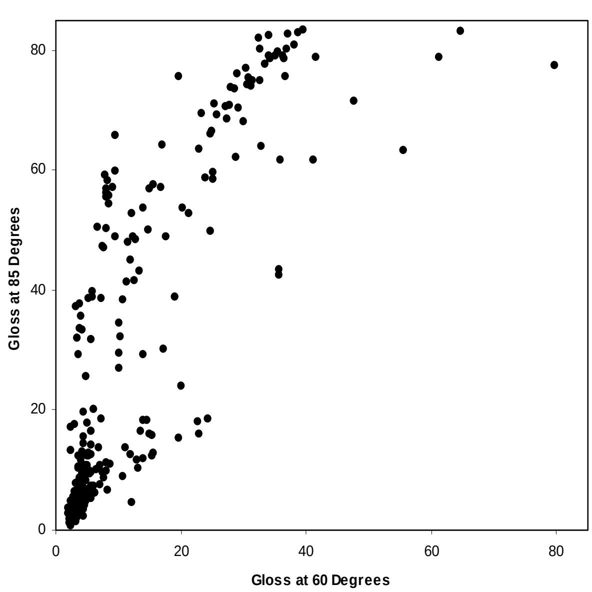

Figure 7. Plot of 60 degree versus 85 degree gloss readings for the print substrate database.

Figure 8 shows the approximate fluorescence of the substrates as estimated with the luminance as measured when the substrates is illuminated with only ultraviolet illumination. Specifically the candelas/meter^2 were measured with a Minolta Chroma Meter CS-100 and the samples were placed in a CTI Color Matching Booth and illuminated with the UV lamp only. This is not a bi-spectral measurement but an approximate integrated measurement. The resulting luminance will be small for non-fluorescing samples and larger for fluorescent samples. In this case roughly half of the media measured had relatively low fluorescence and half exhibited moderate to high fluorescence.

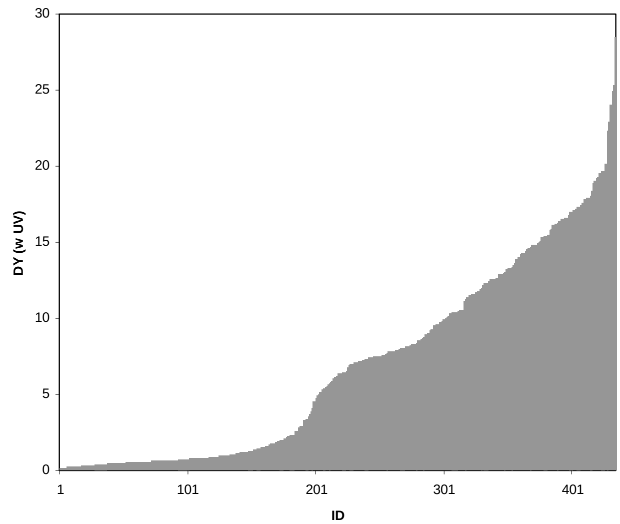

Figure 8. Sorted fluorescence measurements for the print substrate database.

Discussion

The wide range in color, tactile and other surface properties as shown in Figures 1 through 8 demonstrate both opportunities and challenges for future commercial and industrial printing. A wide range of substrates exist and can be used to provide a high-quality affordable modulation of color, tactile and other properties that is simply not possible with an additive display with fixed physical design. These physical differences between the printed page and the displayed page may be an increasingly important aspect consideration in print production. However these differences will require careful characterization and quality control. This will be a challenge given that a micro-bi-spectral-goniometer with multiple backings would be required to measure all of the data shown in the previous sections. This data should also be tied to relevant, mutli-variate perceptual metrics.

At a fundamental level, this data and the implicit inter-relationships also has to be made comprehensible, even intuitive for expert and naïve users alike. To conclude this paper we introduce a tabular visualization of all the properties of the preceding sections. Specifically, the metaphor of the 'periodic table' is used to provide a two-dimensional mapping of proximity to similarity. In this way substrates can differ in a high dimensional space which can then be mapped to a location in a table. Note however this is not entirely an accurate metaphor in that there is no underlying periodicity, such as electron orbitals. A variant of self-organizing map[5] was used which allowed the eleven measurement dimensions under consideration to yield the configuration in Figure 9.

The results shown in Figure 9 are for a portion of a larger tabular visualization of media properties. This table is roughly color coded according to an approximate cluster. The upper left is for bluish, synthetic papers, the lower left is for transparent media, the lower right is for textured media and the upper right is for yellowish media. There is also a clump of metallic media in the central left region and intermediate media that are between clusters shown as un-shaded cells. There many variations on this basic concept but the ability to quantify, navigate and organize the hundreds of substrates, digital finishing effects and print processes is future opportunity for digital print.

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Author Biography

Gary Dispoto is the director of the Print Production Automation Lab, which seeks to streamline the processes required to produce industrial and commercial digital print, enabling new types of printed products and broader access to commercial print production. He holds several U.S. patents related to color imaging. Gary received B.S. and M.S. degrees in electrical engineering from Stanford University and an MBA degree from the University of Santa Clara.

Nathan Moroney is a principal scientist at Hewlett-Packard Laboratories in Palo Alto, California. Previously, he worked for the Barcelona division of Hewlett-Packard and at the RIT Research Corporation. He has a Masters Degree in Color Science from the Munsell Color Science Laboratory of RIT and a Bachelors degree in color science from the Philadelphia University. His is currently researching a range of color imaging topics in the Print Production Automation Lab.

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PPG Industries Teslin 1000 206 gsm / 10 mil	GPA UltraDigital Synthetic Paper 10 mil	Wausau Coated Products 3.4 mil White Flex Vinyl PS Label	Wausau Coated Products Cream Uncoated Estate PS Label	GPA UltraDigital Pearl Ice 110# Cover	Iggesund Invercote Creato 260 gsm / 11.4 pt	CTI Aspire Petallics 98# Cover Beargrass	Mohawk Beckett Expression i-Tone Candlelight Super Smooth 100# Cover
Dunmore Synthetic paper 10 mil	GPA UltraDigital Pearl Gold 110# Cover	GPA UltraDigital White Flex Vinyl 4 mil	GPA UltraDigital Cream Parchment 120# Text	GPA UltraDigital Natural Ribbed 110# Text	Finch Fine iD Vanilla 100# Cover	Mohawk Beckett Expression i-Tone Candlelight Super Smooth 80# Text	CTI Aspire Petallics 80# Text Beargrass
Tekra I81204 - 4 mil White Flexible Vinyl / High Grade Ultra Removable Adhesive / 94 Flat Liner	GPA UltraDigital Pearl Champagne 110# Cover	GPA UltraDigital Pearl Silver 110# Cover	Color My World Heat Transfer paper	Tekra I89160G - 60 lb White Matte Paper Label / Permanent Adhesive	Wausau Coated Products 60# Matte PS Label	Finch Fine iD Vanilla 80# Text	Mohawk STRATHMORE WRITING i-Tone Ultimate White Wove 88# Cover
Dunmore Rigid Vinyl 10 mil	Flex Mag UltraMag Matte Magnet material 14 mil	ICG Holliston Impressions 14 mil	Wausau Coated Products 3.4 mil Clear Flex Vinyl PS Label	Fiberweb Resolution 16 mil	Finch Fine iD Bright White 100# Cover	GPA UltraDigital White Linen 90# Cover	Mohawk STRATHMORE SCRIPT i-Tone Ultimate White Pinstripe 88# Cover
Tekra l11105-5 mil Clear Tipped Polyester	Dunmore Clear polyester 7 mil	Smart Papers Kromekote Frost Pearl for HP Indigo	Tekra I24210K - 10 mil Coated 2 sides White Matte / Matte Rigid Vinyl	GPA UltraDigital 60# Matte PS Label	Neenah Paper Coronado SST Infinite White Stipple 80# Text	Mohawk Via Linen i-Tone Bright White Linen 80# Cover	Neenah Paper Coronado SST Infinite White Stipple 100# Cover

Fig. 9. Portion of a larger 'periodic' table of print substrates.