Color Matching:
Controlling Ink Deposit For Accurate Matches

Do Your Ink Samples Pass the Test?

By Dawn M. Hohl

Color matching is one of most popular points of discussion in the screen printing industry today. Consumer demand for custom colors is increasing and the precision of those matches is becoming more stringent and specific. Screen printers are being compelled to invest in color measuring systems and to hire full time color matching personnel.

Successfully color matching screen printing inks not only requires an understanding of the factors affecting the color and appearance of an ink, but the application of that knowledge when creating test samples to check a new color formulation. The goal of color matching is to create a formulation that will produce the same color on the production floor as in the ink mixing lab. If these efforts fail, costly remixing and rematching must take place while the press sits idle and the job is delayed. Such a situation only costs money.

Three topics will be addressed in this article to assist the screen printer in creating accurate color matches. First the characteristics of screen printing inks and their reaction to light will be explained. Then factors affecting the ink's color and appearance will be discussed, with the final and main topic covering sample preparation methods and recommendations for achieving matches that will hold true on the press.

A better understanding of inks and color coupled with better sampling techniques should provide the screen printer with the opportunity to improve color matching accuracy and speed.

Characteristics of Screen Printing Inks in Color Matching

Before beginning our discussion on screen printing ink characteristics, it is necessary to review the basic reactions of light when striking an object. The four illustrations found in **Figure 1** will help explain these concepts. Light has two main responses to an object. It will either be reflected off of the surface or transmitted through the surface. Four options are possible with these two phenomena.

Reflected light will produce either a specular reflection or a diffuse reflection. When specular reflection **(Figure 1A)** occurs, light will be completely redirected in the opposite direction at the same incident angle from the surface, much like the surface of a mirror. Diffuse reflection **(Figure 1B)** causes the incoming light to be redirected or scattered over a range of angles from the surface.

Transmitted light acts similarly to reflected light generating either a regular transmission or a diffuse transmission. An object that allows the light to pass completely through with little or no interference **(Figure 1C)** is said to have a regular transmission of light. A simple example of this is clear glass. If however the object diffuses or scatters a major portion of the passing light, it is called diffuse transmission **(Figure 1D)** and the object is classified as translucent.

These four responses will occur in all objects in various degrees and combinations to produce the appearance perceived by the human eye. In the case of a screen printed coating, there are actually two objects or surfaces that must be considered. The coating is obviously the primary surface, but the substrate underneath also plays an important role due to the translucency of screen printing inks.

Let us examine the specific effects of light when striking a typical screen

Figure 1

Four Basic Reactions of Light When Striking an Object

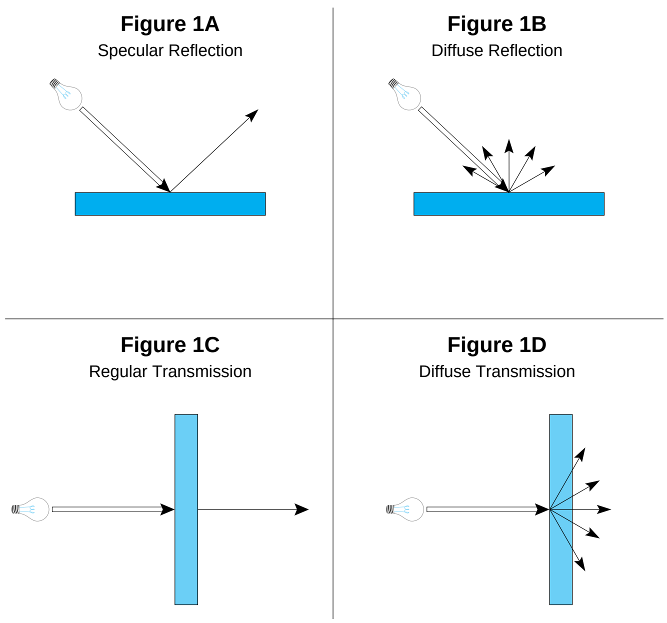
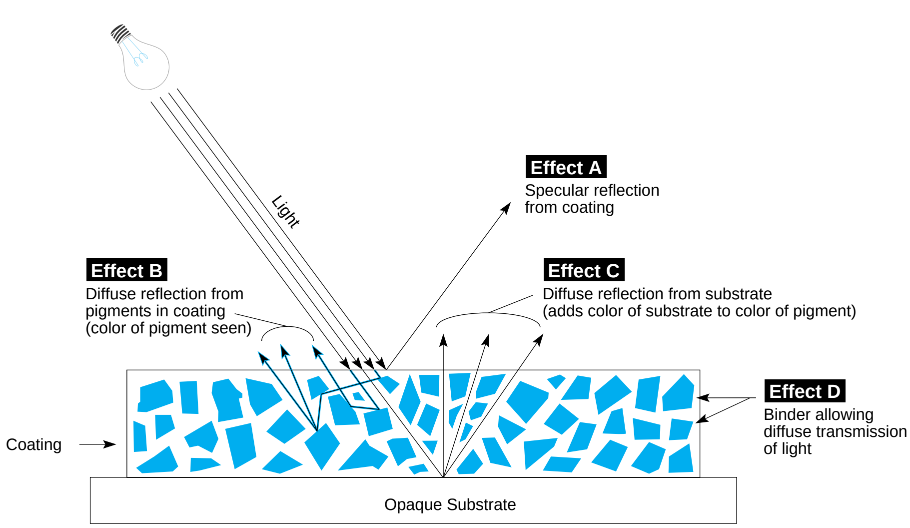


Figure 2

Four Specific Effects of Light
When Striking a Typical Screen Printed Product Printed with Semi-Opaque Ink



printed product printed with semi-opaque ink. In **Figure 2** there are four reactions that can be identified. **Effect A** takes place if the coating has gloss, and takes the form of specular reflection from the top surface of the coating. The second situation, labeled **Effect B,** is responsible for the majority of color perceived by the eye. In this case, the pigment particles present in the coating offer a diffuse reflection of the light causing the color of the pigment to be seen. In **Effect C** diffuse reflection also occurs, but emanates from the surface of the substrate beneath the ink. This reflection will then be blended with the reflection from the pigment particles by the eye producing a combined color. The final reaction, **Effect D,** is important as it allows both B and C to take place. The binder, identified by the clear areas of the illustration, causes light to be diffusely transmitted in the coating making a path for the light to strike both the pigment particles and the substrate.

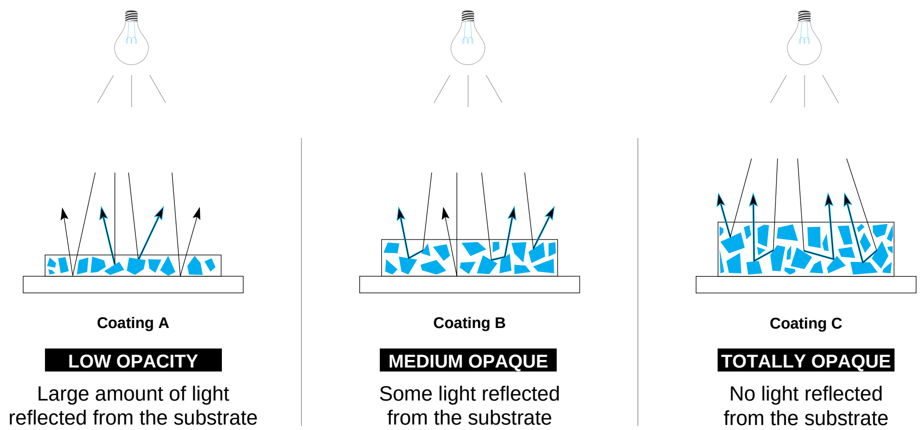
While the above holds true for most semi-opaque inks, transparent inks react entirely different to light. One application that relies on transparent inks is four-color process printing.

Four-color process printing is an application where the inks are basically transparent but are often printed on an opaque substrate. In this instance most of the light is transmitted through the ink coating to the substrate where it is reflected back through the ink to the eye where the color is seen. The sub-strate plays a vital role in the color that is seen from this type of ink.

Extensive explanations of transparent inks is beyond the scope of this paper. There will be some mention of transparent applications in appropriate sections of this paper. Many of the concepts presented can be applied to improve color matching in these type of applications.

Figure 3

As the Ink Thickness of a Coating Increases the Opacity Level also Increases



Factors Affecting Color Perception

Opacity

In the **Figure 2** example of the previous section, the coating is not opaque and cannot completely hide or cover the substrate beneath. The diffuse reflection of the substrate is evidence of this. For a coating to be opaque, there must be enough pigment particles present to block all available paths for light to reach the substrate below. Thicker ink deposits **(Figure 3 and Figure 4)** or a greater pigment load in an ink will increase the opacity or hiding power of a coating. Most screen printing situations do not lay down a completely opaque coating, but rather a translucent one **(Figure 3 Coating A and B and Figure 4 right and middle samples).**

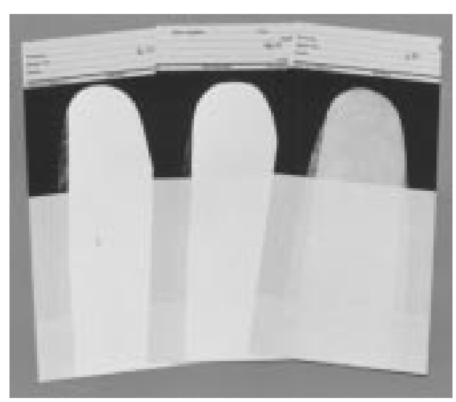
Substrate

With this fact being established, it is clear that the color of the substrate can become a component of the visually perceived color of an ink. It will become, if you like, the final colorant of a formulation. This is especially true when printing transparent inks on opaque substrates, but also occurs with the semi-opaque inks as well. When a colored substrate is used, that same substrate should be chosen to create ink test swatches so the effect of the additional color can be taken into account.

Even white substrates can cause variations in the appearance of an ink. There are in fact many "shades" of white in the different substrates used in screen printing. Different hues and brighteners can often be detected between materials which will contribute to the color of the ink placed on them.

If an image is printed on top of an area that has been previously printed with a different color ink, the appearance of the ink in the new image could be affected in a similar manner.

Figure 4



Three ink samples made on Leneta Cards showing how different thicknesses change opacity.

Subsurface printing with both opaque and transparent inks can also be affected by the substrate. The unprinted side is important in this application since that is where viewing takes place. The gloss and texture on that side can interact with light to affect the color the eye actually sees. These effects will be explained in the following two sections.

Gloss

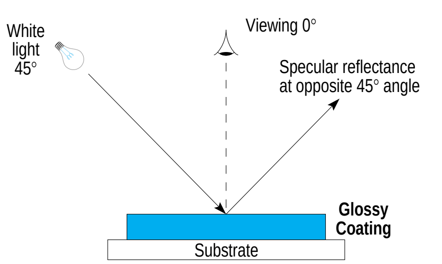
Another very important variable to color and appearance is the gloss of the coating. To understand this effect we will use two samples of the same pigment and thickness, with one having a very glossy surface **(Figure 5A),** and the other a matte surface **(Figure 5B).** If white light is directed on both samples at 45° and the samples are viewed at 0° they will appear different to the eye.

In the glossy sample of **Figure 5A,** the white light of the specular reflection will be directed at 45° in the opposite direction to the incident light. When the sample is viewed at 0°, none of this white light can be detected and only the color itself is seen by the observer. With the matte sample, **Figure 5B,** the white light striking the surface is reflected back at many angles from the surface, causing the color's appearance at 0° to be a combination of ink color and the white light of the diffuse reflection. A perception shift will take place under these conditions making the ink appear lighter in color than the same ink with a glossy quality. An actual example of this phenomena is pictured in **Figure 6.**

In subsurface printing the same effect will take place on the unprinted side of the substrate during viewing. This causes the printed color to appear lighter or darker depending on the gloss of the substrate.

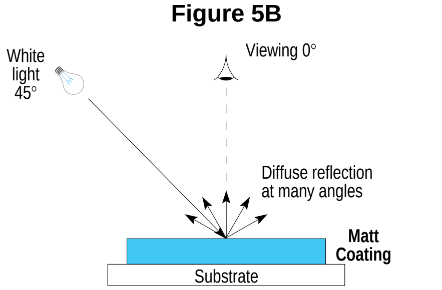
Figure 5

Figure 5A



The white specular reflected light cannot be seen by the observer at a 0° viewing angle, so only the ink's pigment is seen.

Figure 5B



The diffuse white reflection is partially seen by the observer at a 0° viewing angle, and makes the pigment appear lighter than it actually is.

Surface Texture

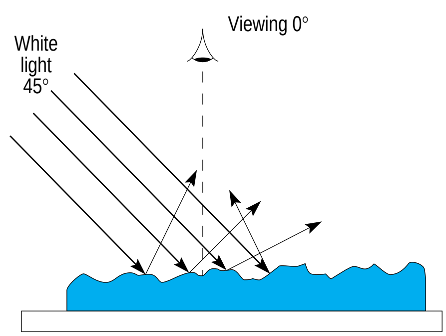
The effects of surface texture are often ignored as being an important consideration when matching a color, but can be a contributing factor in changing the appearance of an object. The effects of surface texture are similar to the observed differences between a glossy and matte sample. A sample possessing a glossy finish but with a rough surface will not react the same to light as a smooth glossy sample **(Figure 7).** As illustrated, a rough glossy surface will reflect a strong specular component of the light, but instead of being directed at the incident angle, the white specular reflection will be created at various angles. The rough texture will in fact direct the reflection in an angle in relation to its surface in a particular area, and in doing so will cause the specular light to be scattered in many directions from the sample. An observer at a 0° viewing situation will see not only the color of the coating and substrate combination, but will perceive white specular light in places as well. The eye blends these together to a certain extent, and concludes the sample to be lighter in color.

Figure 6

Example of the visual difference in the same pigment with a matte and glossy finish (illuminated at 45° and viewed at 0°).

Figure 7

Coating with glossy surface and rough texture



With a glossy but rough or textured surface the specular white reflectance is scattered in many directions. An observer at 0° will see some of this white light, making the coating appear lighter than it really is.

The same phenomena will occur from the substrate when viewing subsurface prints from the unprinted side. Essentially the substrate becomes the new surface of the ink in this situation.

Ink Modification

Keeping in mind the reactions an ink coating has to light, it stands to reason that modification of the ink will change the degree of these reactions. Thinning an ink, for example, will cause a change in the ink's opacity and therefore allow the substrate's color to show through to a greater extent. Adding more solvent to an ink, be it thinner or retarder, creates a lower pigment concentration producing a lower opacity or hiding power at the same deposit thickness. Adding clear to an ink to "extend" its volume will generate the same effect. With transparent inks, addition of solvents or clear base lowers the density of the colors in the same manner.

Should modifications be needed in the production ink, they should be performed to the test formulations in the lab during the color matching process. A good place to add the predetermined percentage of clear or solvent is before a mixed test formulation is drawn down or printed for visual evaluation. The effects of the decreased pigment load can then be taken into account, and adjustments to the formulation or percentage of ink additives can be made accordingly.

A case can be made based on these points for controlling ink modification before and during a print run. In a situation where the press operator adds uncontrolled or excessive amounts of solvents to the ink during the run, there is a high possibility that the batch of ink that matched the desired color in the lab will lose its acceptability on the press for the reasons just explained. Controls introduced to eliminate such problems will pay off very quickly by reducing costly ink remixing, lost press time, job delays, and substrate loss.

Creating an Accurate Sample

Goals in Creating an Ink Sample for Color Matching

There are many testing applications that require the creation of an ink sample. In the context of this paper we have identified color matching of screen printing inks as one of the main applications. Having a clear objective in creating an ink sample will help identify the characteristics that sample should possess. It is important to understand that our goal for creating an ink sample for color matching is to reproduce, in as many ways as possible, the ink deposit characteristics manufactured on the production press. *(More information on lab testing and ink sampling can be found in SPTF's research report entitled "Guideline for Uniform Ink Sample Preparation and Opacity Measurement.")*

The four factors affecting the perception of color, as previously discussed, can then be identified as some important characteristics to keep in mind when creating a sample for color matching. Let us again look at these four factors as they influence the relationship between the ink sample and the production print, and also what controls can be implemented to these factors to increase their correlation. Then the critical issue of ink deposit thickness will be addressed along with some other considerations.

Substrate

Considering the effects of the substrate previously covered, our selection of a substrate to create an ink sample is a very important one. The obvious and best solution that should be practiced is to use the same material for the sample as will be used on the press. By doing so, the effects of the color, gloss, and texture of the substrate that may affect the appearance of an ink will be dealt with. If for some reason this is not possible, a substrate similar in color, gloss, and texture should be selected.

The texture of the substrate can have an influence on appearance. If the surface is rough, the coating will conform to that surface rather than filling in the irregularities. Similarly, a very smooth surface will cause the ink to flow out into a smooth uniform surface.

Subsurface printing brings added importance to the gloss and texture of the substrate. Instead of the ink being viewed directly, it is observed through the substrate. Here the gloss and texture of the substrate may be an added effect to the appearance of the coating. This can cause drastic perception shifts in evaluation of color matches.

Opacity

It has been shown that opacity is related to the deposit thickness and the ink's pigment load. Therefore, to create an accurate sample requires that the same ink and same ink thickness be deposited on the sample as will be produced on the press. Modification of the inks will change the opacity, and in the case of transparent inks the density, of the coating.

The evaluation and measurement of opacity, which as we have seen is related to color, requires a specialized substrate called a Leneta Card **(Seen in Figure 4).** The paper card is half black and half white and has a varnish printed on it to reduce ink absorption into the paper. An ink sample is printed or drawn down over both the black and white areas, allowing the ink's hiding power to be determined. Visual evaluation of opacity is easily accomplished, but with a spectrophotometer or colorimeter the contrast ratio can be measured and calculated. *(A detailed discussion on contrast ratio is beyond the scope of this paper, please contact SPTF for more information.)*

Testing opacity is useful in performing incoming quality control checks on inks that will be used in color matching applications. These types of checks help ensure that drastic variations are not present in the area of opaqueness between batch to batch of ink coming into the plant. With opacity being an important element to color matching, incoming control checks on the inks become very useful and can save money in the long run.

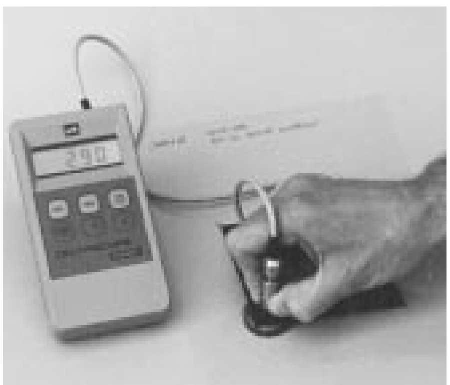
Gloss

The gloss of an ink surface can make a difference in appearance as we have explained. The gloss properties of an ink are often inherent in its formulation, but sometimes can be modified with additives. Some ink lines will have a gloss or matte finish identified in the specifications. If gloss is a critical element in the print

Figure 8

Micrometers are inexpensive and very useful for measuring dry ink deposit thickness.

Figure 9



Electronic instruments working on a magnetic induction principle are used for measuring dry ink deposit, stencil thickness and fabric thickness.

Figure 10

Eddy current instruments are similar to magnetic induction devices, and are capable of measuring the same type of variables.

appearance, a gloss meter can be used to measure and control gloss level. The glossmeter can also be used to measure the substrate when gloss is important in subsurface applications.

Matching an ink to a color swatch supplied by the customer can pose some gloss concerns. If the ink doesn't match the gloss level of the swatch, the formulation may have to be adjusted to match the color. If gloss is a major factor when matching inks, the first step is to try to achieve the proper gloss to the ink, and then modify for color.

Texture

As mentioned, the texture of the substrate can affect the ink in various ways to cause a change in color perception. The ink itself may also carry a texture when it has been printed on a substrate. Very thick inks have a tendency to produce a screen like surface in the printed deposit. In most cases however, the effect of the screen on the deposit's surface is minimal. Regardless, it is good to keep the effect of texture in mind when creating an ink sample.

A good tool to help characterize surfaces is a surface profilometer, which measures surface roughness in Rz units. These devices can measure the roughness of either the ink or the substrate (in subsurface applications) when texture is an issue in the appearance of the color. Surface profilometers are best known for their usefulness in the evaluation of stencil roughness, and are available from several manufacturers.

Ink Thickness

Ink thickness is a critical factor that can and must be controlled in an ink sample. Its effect on the appearance of a color cannot be underestimated. In order to control ink thickness, an accurate and repeatable method for measuring it must be established.

There are many instruments and devices on the market that are designed for wet and dry ink thickness measurement. These instruments have a wide range of sophistication and price. A discussion on all these devices is out of the scope of this paper, but detailed information on this topic is covered in SPTF's three part research report entitled "A Guideline to Wet and Dry Ink Deposit Measurement Methods." A brief explanation of two of these instruments is necessary to define a general procedure for measuring and controlling ink deposit in color matching applications.

There are two physical states where an ink deposit can be measured. When an ink is just printed and wet, or when it has been dried or cured. Dry deposit thickness is generally easier to measure than wet thickness and is the best condition for printers to deal with. Devices especially useful for dry measurements are micrometers **(Figure 8)** and electronic instruments working on the magnetic induction principle **(Figure 9)** or working on the eddy current principle **(Figure 10)**. All of these devices are easy to use and provide accurate readings when used correctly. Micrometers tend to be less expensive (depending on the options) than electronic measurement instruments. However, additional applications can be fulfilled with electronic devices that cannot be performed with a micrometer, including the measurement of stencil thickness and fabric thickness. All three are equally appropriate to use for measuring dry ink deposit thickness.

Wet ink thickness measurements can offer interesting information to supplement the dry data, and will help in further characterizing production prints and ink samples. For those interested in measuring wet ink thickness, an Electronic Micro Gauge is recommended. More information on this instrument can be found in Part I of *Guideline to Wet and Dry Ink Deposit Measurement Methods.*

At this point a special comment on measuring the ink deposit on UV curable inks is necessary. SPTF research has confirmed that UV inks shrink in thickness anywhere from 25-50% when they are cured. *(This research is included in the SPTF research report entitled "Polyester Mesh Capability Study with UV Inks.")* Therefore the dry thickness measured cannot be directly related to the wet thickness unless previous testing confirms that that particular ink has a consistent shrink rate at a certain ink thickness. Incorrect conclusions will occur if only a 2% reduction of wet to dry thickness is assumed.

The curing conditions when testing UV inks are important and should approximate those that will be used in production. Important factors include belt speed, lamp wattage, heat and substrate. A radiometer will help quantify the amount of light seen by an ink sample. If the UV ink is not fully cured the dry thickness will vary and will not be reliable. The time of the dry measurement is also important and should be standardized as UV inks undergo a post cure. To date the effects of post curing in UV inks has not been researched by the SPTF. It is unknown whether additional shrinkage occurs during this time. In any case, care should be taken when working with UV inks to standardize the curing conditions for the sample deposits according to the production conditions that will be used. This is especially necessary if only dry ink thicknesses are being measured and used in color matching.

Once a measurement tool has been identified, the dry thickness of the ink printed on the production press must be determined. In order to obtain relevant information on a specific color matching job, the basic conditions that will be used to ultimately print that job should be used when testing for the dry ink thickness. This may require a test run on the production press with the appropriate conditions if the information can not be obtained from prints on an actual run having the same or similar conditions. Documenting results from each set of conditions tested on the press will establish a database that can be used in the future and can be an invaluable tool in color matching.

Conditions that are important include mesh count, tension, ink (with any modification that will be used), squeegee durometer, squeegee pressure, squeegee angle, off-contact and substrate just to name a few. Some of these conditions are more critical and should be ensured, while others do not affect the outcome as much. The ink, substrate and mesh are all extremely influential elements that should be kept identical to actual run conditions.

There are obviously many other factors not specifically mentioned here. The overall rule is to have as many conditions as possible the same or similar to run conditions for a particular job when testing for dry ink deposit. Once this is achieved, the deposit needs to be measured with the selected instrument, and the dry ink deposit calculated *(subtract substrate measurement from ink/substrate combination measurement)*. With this in hand, an accurate ink sample can be made during the color matching process, leading to a match that can be easily achieved and maintained on the press.

It is important to note that ink deposit thicknesses may be different between image areas that *are not* affected by the stencil thickness, and those that are smaller and *are* influenced by the stencil thickness. The printer will have to determine which one is important in relation to the application or image being printing. If, for example, the image that was being printed only had large areas present, the ink thickness not affected by stencil thickness should be measured on the production press print. On the other hand, if a four-color process job was being printed, the ink deposit will be influenced by stencil thickness, and this thickness should be measured. Whichever one is selected should be the thickness that is reproduced in the color lab. To ignore this procedure will decrease the chance that the ink mixed and matched in the lab will match on the production run.

In order to take these measurements, samples must first be printed on the production press using an image with a larger open area and a halftone dot area, or they may be obtained in an actual run containing these areas. To measure the thickness in an open area simply take 5-10 measurements either with a micrometer or electronic device in the center area, being careful to not contact the edges of the image. With small image areas, the easiest way to measure thickness is to use a disk micrometer in a mid-tone dot area of a halftone or another type of consistent small image area that is being printed. Again 5-10 measurements should be taken and averaged to get a deposit thickness reading. When using a micrometer, the slip ring should be used at all times to control the pressure of the measurement. The electronic devices will not be as effective for small image area measurements due to the small size of their probes.

Other Considerations

When evaluating and formulating color with a spectrophotometer, gloss and texture may become a big concern. Spectrophotometers come in various geometries which obtain measurements in different ways. The two main types are a 0°/45° geometry, and d/8° diffuse sphere geometry (specular component included). The main difference is one takes into account the texture and gloss effect as well as the color (0°/45° geometry) and the other identifies only color shifts due to pigment changes (d/8° diffuse sphere geometry with specular included). The printer must determine what attributes are important to measure, and select the appropriate measurement geometry to meet those needs. A detailed discussion on these concepts can be found in other articles on color measurement equipment, and will not be covered here.

Sample Generation Methods and Recommendations

There are several widely used methods for creating ink deposits in a laboratory setting. Two of these, wire wound bars and open gates or blades, use special devices to lay down the ink. The third main category to be discussed is proofing using screen printing. There are many variations of these three methods so only the general concepts will be explained. The Screen Printing Technical Foundation has done a great deal of research in these areas. A brief overview of these findings will be presented, and recommendations made based on this information.

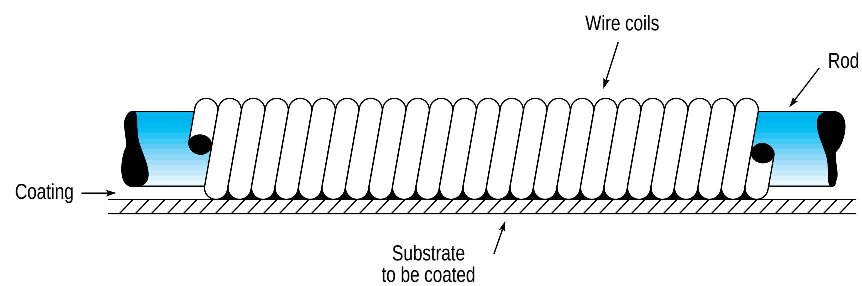
The accuracy, repeatability and reproducibility of ink deposit systems used for sample preparation is of vital importance. Evaluations of the systems emphasized in this paper were approached with respect to these three points.

Wire Wound Draw Down Bars

One of the most popular methods being used to produce ink samples is wire wound draw down bars. As the name implies, an ink deposit is created by drawing ink across the surface of a substrate with a bar designed to meter a specific quantity of ink. The bar provides this metering action through cavities created by a wire wrapped tightly around the length of the steel rod, as illustrated in **Figure 11.** Because the cavity between the wires determines how much ink will flow through the rod, different wire diameters will produce different thicknesses, and the bars are rated in this fashion.

Figure 11

Enlarged Detail of Wire Wound Rod



The diameter of wire determines the amount of coating going through the space or groove created.

Once the ink is metered onto the substrate by the bar, it will flow to a state of equilibrium. Theoretically, an ideal flow out would eliminate all traces of the peaks and valleys made by the wire and would result in a perfectly smooth and uniform ink deposit. In reality, an ink's equilibrium state is somewhere between these two extremes and is dependent on the ink's rheology, viscosity, and surface tension interactions. Highly viscous inks like plastisol and process inks produce extremely irregular deposits because they do not flow much, and are not suitable for wire wound bars.

The basic process for producing a deposit with a wire wound bar consists of several important steps. First, the substrate is placed on either a surface plate or a vacuum plate which provides a means of securing the substrate and supplies a flat surface to make the draw down. The draw down motion of the bar itself can be accomplished manually or with an automated system having speed and pressure controls. A measure of ink is placed at the top of the substrate, the bar is placed above the ink in contact with the substrate and drawn down the length of the substrate with uniform speed and pressure.

SPTF research on wire wound coating systems has been extensive and cannot be presented in its entirety. However, several conclusions were reached from this research that are appropriate for our discussion on color matching. Two graphs, **Figure 12** and **13**, can help evaluate wire wound draw down systems in the three areas of accuracy, repeatability, and reproducibility. The results in these graphs are representative of the findings obtained from many other experiments on wire wound systems. The suggested conclusions are not being drawn from Figures 12 and 13 alone, but rather on all the tests performed at SPTF which produced similar results.

In **Figure 12**, a standard wire wound bar rated for a 24 micron deposit was tested over a range of draw down speeds. An automated coating device was used in SPTF's testing to eliminate human variation. This automated system ensured the bar traveled evenly across the length of the draw down, and applied fixed pressure and speed. The speed could be adjusted over a range of settings, producing different shearing forces on the ink. Nine of these settings were selected for this test, while all other conditions were kept the same. A standard multipurpose UV ink was used on a ground glass substrate. Wet ink deposit thickness was measured in ten places on each sample with an Electronic Micro Gauge.

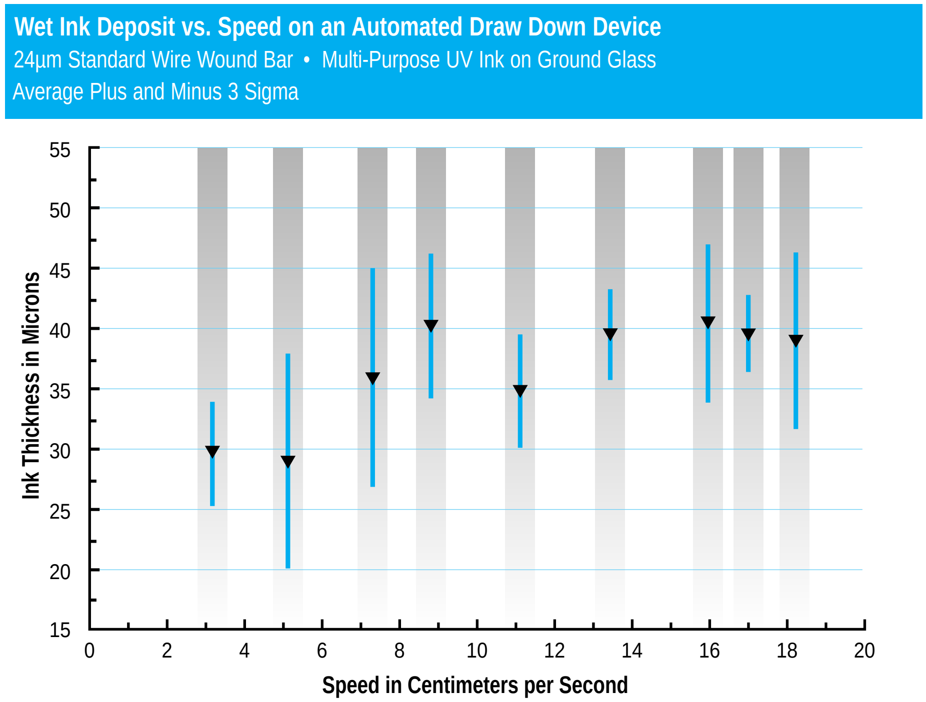
The graph depicts the average (triangle) and process spread (vertical line running through triangle *based on plus and minus three standard deviations*) of each of the nine samples. The dotted line represents the rated thickness of the bar at 24 microns. The first inference made is that the bar does not produce a 24 micron deposit with any of the speed settings under the conditions of the test. The average deposit thickness range is about 29 microns to 40 microns. This average varies irregularly over the range of speeds tested. It is highly probable that while the increase in shear may be affecting the reaction of the ink to cause some of this unpredictable variation, other factors are more than likely coming into play as well. If the variation was due solely to rheological reactions of the ink, a more definable pattern would be evident in the results.

In addition to the differences in the average ink deposit thicknesses, the process spread for each of the samples vary indiscriminately as well. In some cases the spread is very tight indicating good thickness uniformity across the sample, while in others the spread is very wide characterizing it as irregular. Again, there is no pattern to the increase or reduction of the process spread at different speeds. This is another indication that other unidentified factors are causing drastic variations in the ink deposition process.

The reference to repeatability of a system can be defined as how much deviation from the average occurs in each ink sample. The less deviation the more repeatable the process. Another term used for this is precision. The process spread is a good method of determining the repeatability of a process as it defines the ends of a normal frequency distribution (or bell shape curve) using the standard deviation of the data.

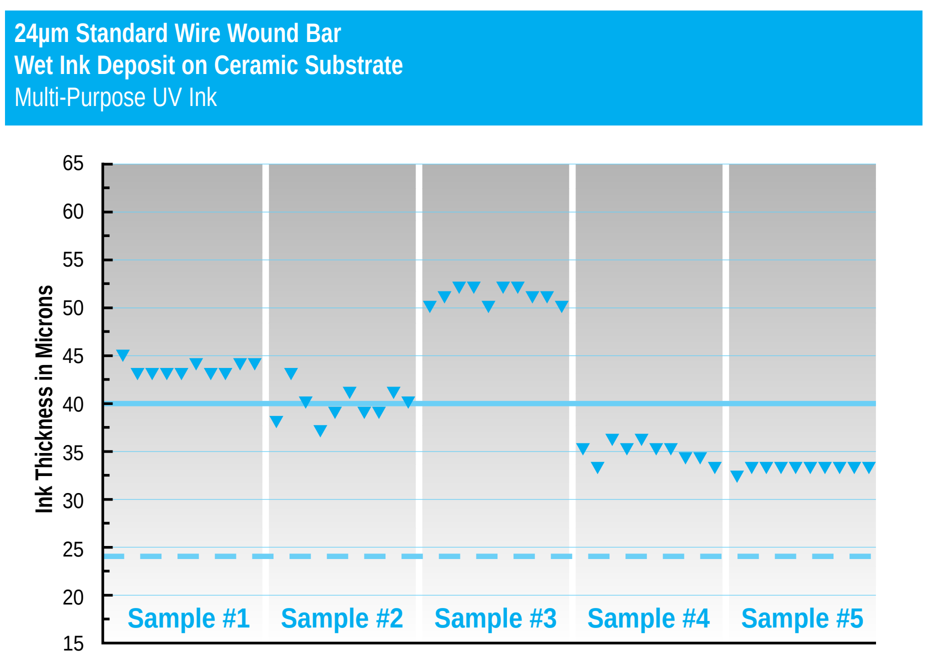
The results of **Figure 12** address the issues of accuracy and repeatability, and clearly indicate that the rated bar thickness is not reliable, and the process spread or repeatability of ink deposit thickness from sample to sample varies to a great degree. It is safe to assume that manual draw downs with wire wound bars will have less

Figure 12



Testing the accuracy and repeatability of the wire wound draw down bars over nine speed settings demonstrates that none of the deposits produced the thickness rating of the bar (24 microns), and the process spread varied erratically indicating poor uniformity and repeatability.

Figure 13



Wire wound bars failed to reproduce the same deposit thickness consistently under standard conditions even when a ceramic substrate flat to within .75 microns was used.

consistency than those shown here made with an automated system. Based on this information wire wound systems rate poorly in both of these areas.

In an attempt to isolate these unidentified factors causing erratic results, SPTF replaced the ground glass substrate with a 7" x 11" ceramic block ground flat to 0.75 microns across the entire surface. This sufficiently eliminated the effect of an uneven substrate and gives a picture of the true capability of the process. The speed was kept the same, with the pressure and ink constant as well. The graph shown in **Figure 13** illustrates these results. The ten measured points on each of the five samples are plotted individually as triangles, with the solid line representing the average ink deposit thickness of all five samples, and the dotted line again showing the 24 micron bar rating.

Notice the average ink deposit is around 40 microns, 16 microns greater than the bar rating. A second interesting point is that within each sample the uniformity of the deposit is consistently better. That is, there is little deviation in ink thickness in the ten data points in any one sample. However, there is a fairly large difference in ink deposit thickness between some of the samples. Sample #3 measured around 51 microns while sample #5 falls in around 33 microns. Considering that all conditions for producing both samples were kept the same and the substrate is not a factor, these differences become somewhat of a mystery. The conclusion must be that wire wound bars fail to reproduce the same deposits sample to sample under standard conditions. In the area of reproducibility the bars are rated poorly as well.

Based on these research results, SPTF is not recommending the use of wire wound draw down bars for testing screen printing inks. Unpredictability is the best term to describe the results SPTF has seen from wire wound draw down bars. Accurate color matching leaves no room for unpredictable samples. If these bars are currently being used in the color matching process they are more than likely causing problems and should be replaced with a more dependable method. SPTF has made attempts to improve the accuracy, repeatability and reproducibility of ink deposits produced with the wire wound bars, but has not been successful. Other types of bars were also tested at SPTF but did not yield significant improvements over the results presented here. The inconsistencies with this method seem to be inherit in the system, and cannot be overcome using simple techniques. The next two methods are far better than wire wound systems and should be considered as alternatives.

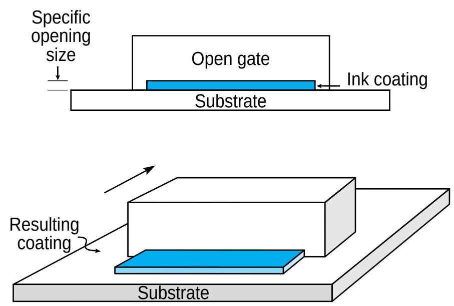
Open Gate Systems

Another common technique for producing ink deposits involves an open gate or blade device. The basic concept is simple **(Figure 14).** A precise notch or opening is cut out of the bottom of a piece of steel or aluminum, a portion of ink is placed on the substrate, and the notched device is drawn across the ink over the length of the substrate. The opening in the blade meters a certain thickness of ink onto the substrate. The actual ink thickness produced can vary 40% to 80% of the opening size specification. Unlike the bars, the opening or gap size is specified rather than the deposit thickness. The actual thickness deposited depends not only on the size of the gap, but from other key factors like the ink and substrate, and will vary with test conditions.

The surface or base on which the substrate is placed when a drawdown is made is very important. Draw down base's are sold specifically for this application. The base's flatness and uniformity will have an impact on the resulting deposit.

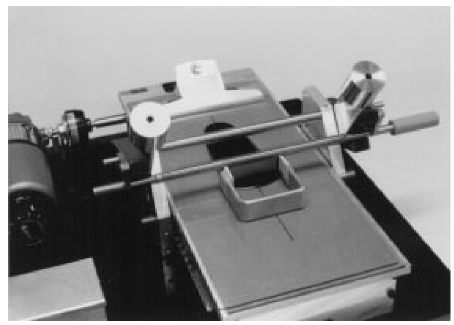
The draw down action can be accomplished either manually or can be rigged for automation on the same system designed for wire wound bars **(Figure 15).** Automation is again preferred to manual methods to eliminate operator variation on speed and pressure. Almost all SPTF research on open gate systems was conducted using an automated system. There are two general types of open gate or blade systems that were tested; fixed open gates and adjustable open gates.

Figure 14



The basic design of an open gate or blade consists of a precise notch or opening cut out of a piece of steel or aluminum where ink is allowed to flow through during the deposition process.

Figure 15



Open gate systems can be rigged for automation on the same system designed for wire wound bars with little modification.

Figure 16

Two fixed open gate devices each having eight different opening sizes.

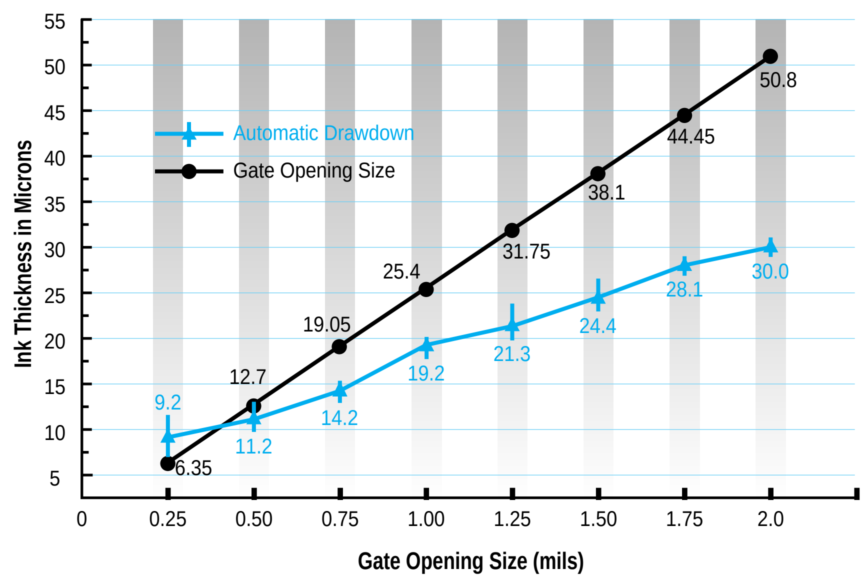
Fixed Open Gate Devices

The first type to be discussed will be called a fixed open gate because it has opening sizes that cannot be modified. The photograph in **Figure 16** shows two fixed open gate devices each having 8 different opening sizes. Of the two pictured, one has opening sizes from 1 to 8 mils in increments of 1 mil, while the second was custom made to have openings of 0.25 mils to 2 mils in increments of 0.25 mils. The custom made model produces ink deposit thicknesses more typical to general screen printing. SPTF recommends a custom fixed open gate device with opening sizes starting at 0.75 mils to 2.50 mils in 0.25 mil increments for the range to best represent general screen printing. SPTF tested the tolerance of the machined notch depths and found the standard model less precise than the custom made one. These tolerance differences can influence the resulting ink deposit. When purchasing these devices it is best to pay a little extra for close tolerance manufacturing of the specified notch sizes. The approximate price of these devices ranges from $150 to $350.

SPTF research on fixed open gate systems was again extensive, and cannot be presented in its entirety here. Four representative graphs **(Figures 17, 18, 19, and 20)** will allow us to make some general conclusions in the three areas of concern, accuracy, repeatability, and reproducibility. All of this data was obtained using a custom made fixed open gate which reflects thicknesses typical to screen printing. The draw downs were accomplished with an automated system rigged to drive the open gate device **(Figure 15)** so pressure and speed could be controlled. An exception was made in **Figure 19** where several manual samples were made. A multi-purpose UV ink was used for most of these tests, with other inks being noted. The ceramic substrate mentioned previously was used in all of the tests presented here. SPTF has tested

Figure 17

Custom Fixed Open Gate
Wet Ink Deposit on Ceramic Substrate
Multi-Purpose UV Ink



Ink deposits produced under standard conditions on each of the eight openings of a custom made fixed open gate device yielded a linear relationship and very good process spreads.

five other substrates including polycarbonate, coated paper, vinyl, polyester and glass, all with equally good results. Wet ink deposits were measured with an Electronic Micro Gauge (EMG) in all instances.

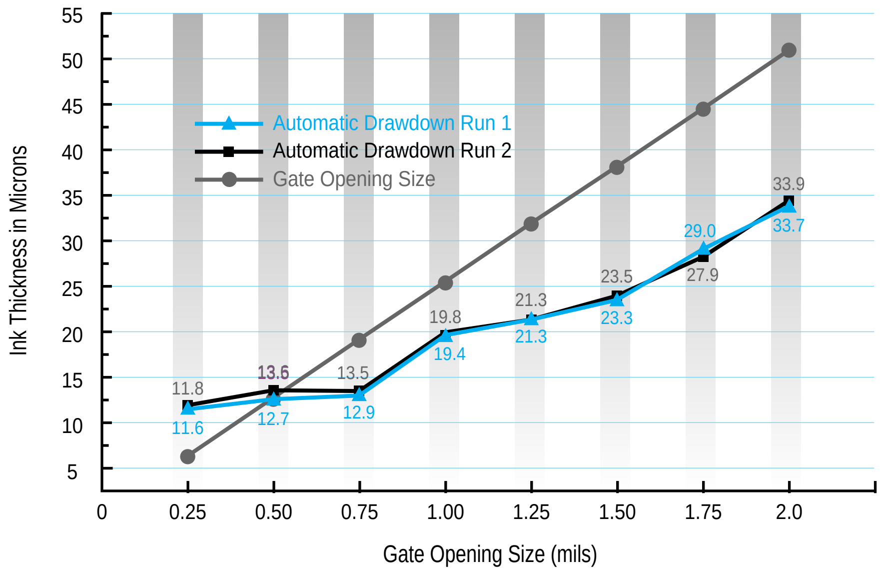
The graph in **Figure 17** represents the actual ink deposit produced from each of the eight opening sizes on the custom fixed open gate device tested with one speed setting. The opening sizes are represented by the points on the black line, and the actual ink deposit by the blue data points corresponding to the opening size. The process spread for each ink deposit sample is also pictured with the blue vertical line running through each point.

There are several things we can notice from this graph. The most obvious is that the ink deposit thickness does not match the opening size. As stated earlier, the ink deposit can be anywhere from 40-80% less than the opening size as specified with the open gate devices. Notice also that there is not a constant offset from the opening size to the resulting deposit for all the opening sizes present. This is due to the inks reaction to different shear rates that are created with the different opening sizes. The positive benefit is that the ink responds in a predictable pattern to the different shear rates resulting from the different opening sizes. The pattern is basically linear, just as the opening size range, but has a different angle or slope. The actual slope and position of the line in relation to the opening size line is dependent upon the ink's reaction to shear rate.

A second interesting thing on this graph is the crossing over of the actual ink deposit line on the opening size line at the .50 and .25 mil gate openings. How can more ink be deposited than the opening size allows? The answer lies not only in the ink's reaction to the increasing shear rate at these low opening sizes, but the effect of this reaction on the pressure being used in the draw down action. If this pressure is not sufficient to overcome the resistance of the ink to flow at high shear rates, the gate will begin to lift up and hydroplane on the ink. This in turn

Figure 18

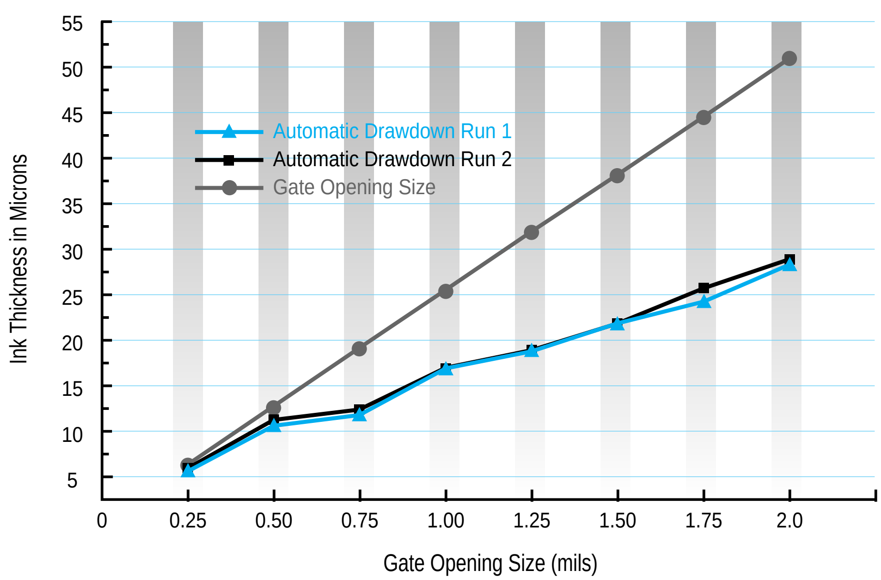
Custom Fixed Open Gate
Wet Ink Deposit on Ceramic Substrate
Multi-Purpose UV Ink



Sample to sample reproducibility results were excellent when deposits with the custom fixed open gate were run twice under standard conditions with the automatic method.

Figure 19

Custom Fixed Open Gate
Wet Ink Deposit on Ceramic Substrate
Multi-Purpose UV Ink



Draw downs made by hand with the custom fixed open gate were equally reproducible to the automatic results.

will cause more ink to be deposited on the substrate.

The pressure therefore, is extremely important in fixed open gate draw downs. SPTF research indicates that the placement or position of the pressure is important as well as how much pressure is applied. In both manual and automated draw downs with a fixed open gate, the majority of the pressure should be positioned close to the actual side making the deposit. The amount of pressure needed is dependent on the ink type and its resistance to shear rates produced. Testing may be required to arrive at a workable pressure level for various inks. Please note that even with the insufficient but standardized pressure used in **Figure 18,** the results are still reproducible.

With all this in mind it is apparent that each ink will produce its own characteristic curve under a given set of conditions. This repeatable characteristic curve can be used for predicting the actual ink deposit from a given opening size, and allows the color matcher to select the correct opening size to achieve desired results. Without a doubt, the deposit curve produced with the open gate systems makes it possible to create accurate ink samples with relative ease.

Sample uniformity and repeatability are the next areas that need to be assessed. In **Figure 17** each sample is represented with a process spread (vertical line through each average data point) which is the average plus and minus 3 standard deviations. The spreads are extremely small with the worst case being only 5 microns. This means that most of the samples probably varied only 1 to 2 microns in the area measured, indicating they are exceptionally uniform and repeatable with the ink tested here. Thicker inks such as plastisol and process inks may decrease this uniformity to a degree, but SPTF testing has proven this to be minimal and the fixed open gate is still far superior to deposits produced with wire wound bars.

To address reproducibility we will look at **Figure 18** where the test to generate the characteristic curve for the multipurpose UV ink was performed twice with the automatic system under identical conditions. The results show how reproducible the ink deposits are from sample to sample. We see that the two deposits produced under identical conditions for all the opening sizes are very consistent overall, and the basic linear line produced maintains its slope and position.

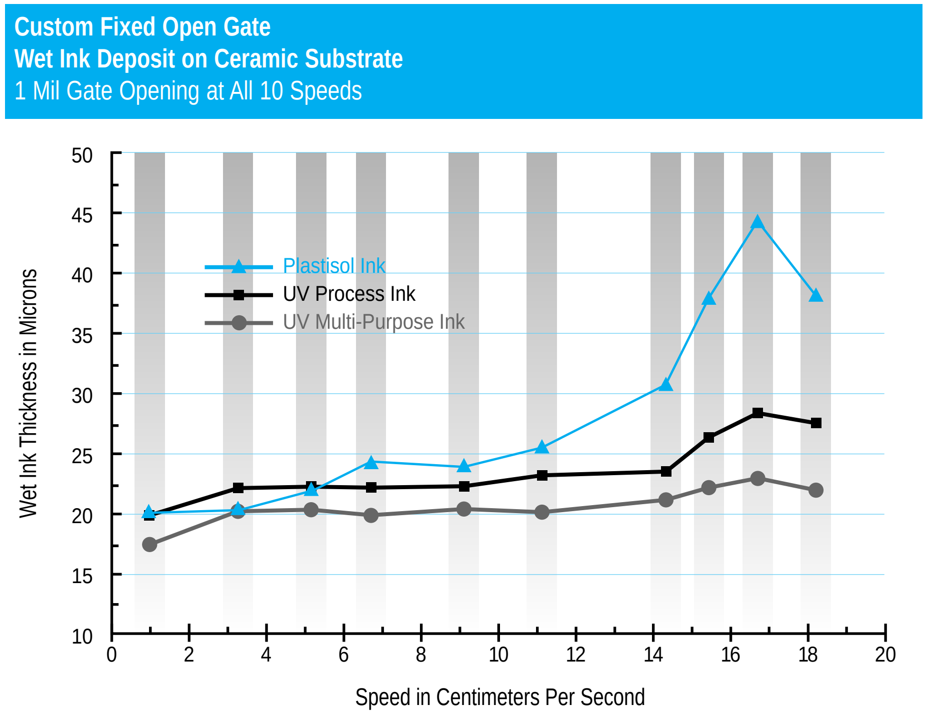
The same test for reproducibility was conducted for samples that were drawn down by hand, and is shown in **Figure 19.** The results were equally as reproducible, although the deposits are slightly thinner than was produced with the automatic method. A possible explanation for these thinner deposits could be that more pressure was used in the manual tests than on the automatic ones.

Next to be discussed is how draw down speed affects ink deposits on open gate systems. A similar test to that presented in the wire wound section was conducted on three different inks for the custom fixed open gate. The three inks include a multi-purpose UV ink, a process UV ink, and a plastisol ink. One opening size was selected (1 mil in this case) and deposits were produced under ten different speeds. The results are found in **Figure 20.** Unlike the wire wound bars, the open gate produces virtually the same deposit thickness for most of the speed settings tested. The high shear rates created with the faster speeds did cause some variation in ink thickness, but these speeds are extremely fast and are not appropriate for making draw downs.

It is important to remember that different inks will produce different deposits under varying shear rates. With variation in speed under the same opening size, the shear rate will change. (Shear rate is calculated by dividing the velocity or speed by the gap size.) Each ink will have a different characteristic curve for a certain set of conditions, and must be retested when a vital parameter is changed.

The research results leave no doubt that, in all points tested, the fixed open gate systems far supersede the wire wound bars in performance and reliability. To use fixed open gate systems effectively however, accurate characteristic curves must be generated under a defined set of conditions including speed, pressure, rheology, substrate, opening size, and amount of ink. While this process may seem burdensome, the benefits of precise and repeatable ink samples far outweigh the minimal time spent to characterize a set of conditions for testing. Ink samples may be produced in a shorter period of time without these measures, but in the end inaccurate samples can cause problems costing far more money than was saved.

Figure 20



Three different types of ink were tested on a single opening size over 10 speed settings and shows that the typical speeds used for these draw downs produce consistent ink thicknesses.

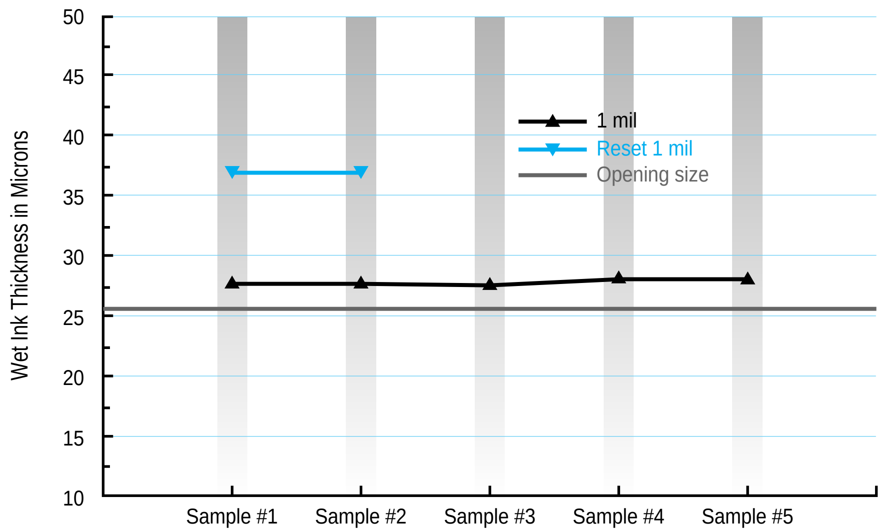
Adjustable Open Gate Devices

The second kind of open gate system, the adjustable open gate, consists of a single device that can be adjusted to create a wide range of opening sizes. Prices for adjustable systems generally range from $360 to $400. Theoretically, the added adjustability would give the user the ability to create any desired opening size with one device. However, if it is difficult to reset a specific opening size over and over again, reproducibility is lost and testing must take place each time the device is adjusted. The option of adjustability should be considered with caution as it may actually complicate testing procedures rather then helping them.

There are many different devices falling in this adjustable category. Some have a more accurate method for changing the opening size than others. For this reason an overall statement regarding accuracy, repeatability and reproducibility on adjustable open gate systems cannot be made. Individual evaluations must be made on each system.

Figure 21

Adjustable Open Gate
1 Mil Opening on Ground Glass



The adjustable type of open gate tested at SPTF produced poor results when the opening size was reset.

SPTF has tested one type of adjustable open gate with a 0 to 10 mil range. The main goal of the test was to determine the reset reproducibility of the blade. The blade was first set to a one mil opening size and five ink deposits made **(black line Figure 21).** The device was then carefully reset to one mil, and ink deposits again produced under the same conditions **(blue line Figure 21).** Two different ink thicknesses resulted, presumably from the same setting, one being around 28 microns and the other around 37 microns. These are significant differences when color matching inks. We can conclude that this particular device has difficulties associated with setting the opening size repeatedly to reproduce a specific deposit thickness. While this conclusion applies to the particular brand SPTF tested, all adjustable open gate devices are suspect to reset problems and should be thoroughly tested before they are relied on.

Creating Ink Samples Using Screen Printing

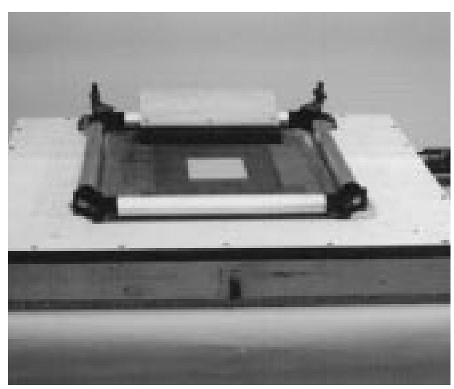
The final method of creating ink samples uses the screen printing process. The technique is simply defined as using a manual or automatic screen printing proofing press to create ink samples for color matching. The object here is to have a separate small format screen printing setup dedicated to color proofing in the ink lab environment.

There are many small format presses on the market that are useful for creating ink samples. The first class is a manual or hand printing setup, which can take many forms. The simplest and least expensive option is to build a hand printing setup **(Figure 22)** with hinges and a vacuum base for securing the substrate. For greater control a manual press can be purchased such as the one pictured in **Figure 23.** This unit offers off-contact adjustments, vacuum hold down, registration adjustments, and screen counterbalancing, making it somewhat easier to use than a home made model. Another example of a manual proofing press is shown in **Figure 24**. Features on this model include 12" x 12" retensionable frames, a vacuum generator (using compressed air), adjustable off contact, and horizontal screen lift.

With all of the manual screen printing presses, the actual printing is done by a operator with a hand held squeegee. Using manual presses to produce samples requires that the operator be skilled and fairly consistent in the printing motion for repeatable results to be achieved. Naturally, different operators will have slightly different printing patterns potentially resulting in different ink deposits from the same set up. For this reason standard conditions and procedures should be established in every area possible, especially squeegee durometer, angle, speed, and pressure; screen flooding; ink type and viscosity; off-contact; test image; and substrate. The more control that is implemented in these areas the more consistent the ink deposits will be.

The second class of proofing press consists of small format semi-automatic press like the one pictured in **Figure 25.** With the squeegee and flood stroke automatically driven, the printing results are far more consistent and repeatable than with a manual press. The major disadvantage with this option is the higher cost of the press. However, this must be weighed with the advantage of eliminated operator

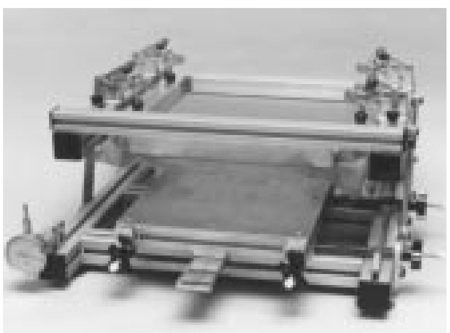
Figure 22



The simplest and least expensive screen printing proofing press is a home built hand printing setup.

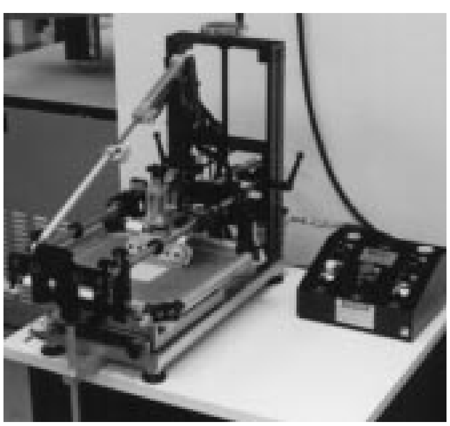
Figure 23

Figure 24



Figures 23 and 24: More sophisticated manual screen printing presses can be purchased for proofing purposes.

Figure 25



A small format semi-automatic press is an excellent option for proofing inks with the screen printing process.

variation and added control of press variables.

Even with a semi-automatic press, conditions and procedures must be standardized to ensure consistent results. The additional controls offered on these presses make this easier to accomplish than on the manual presses.

Ink Deposit Thickness

Ink deposit thickness is still an issue demanding attention, even when using screen printing to produce ink samples. Just as with the fixed open gate system, the deposit produced on the production press must first be determined. The re-creation of that thickness is the primary goal no matter what ink sampling method is chosen. **A lab proofing press will not necessarily produce the same ink deposit as a production press when using the same mesh, ink, and substrate.**

Production presses print differently, and may produce a different deposit than a manual or automatic proofing press with the same mesh count, ink, and substrate. It may be necessary to use a different mesh count on the proofing press to create the same ink deposit as will be generated in production.

This bring us to another important point to keep in mind when selecting a mesh count to deposit a certain thickness of ink. Current theory says that mesh count directly relates to the ink deposit thickness produced. The assumption has been that with each progressively higher mesh count, less ink will be deposited. SPTF research has shown this to be untrue. Wet ink deposits made with a multipurpose UV ink were measured on fifteen different mesh counts ranging from 109 to 508 **(Figure 26).** While there is a declining ink deposit trend from the 109 to 254 mesh count range, the curve flattens at that point through to the 508 mesh. These findings then indicate that the deposit thickness resulting from the mesh alone (stencil thickness effect was not taken into account) is **not** connected with a fabric's mesh count.

As a result of this research, SPTF uncovered a link between *measured* fabric thickness at tension and ink deposit thickness. A formula was developed from this relationship that predicts the wet ink deposit produced by a mesh. This formula is most useful for meshes above a mesh count of 230 threads per inch, but **should not be applied to plain weave meshes of 355 threads per inch and above.** The calculation is as follows:

$$IH = Ft^* \times 0.28499$$

IH – Estimated ink deposit thickness

Ft – Measured fabric thickness at tension

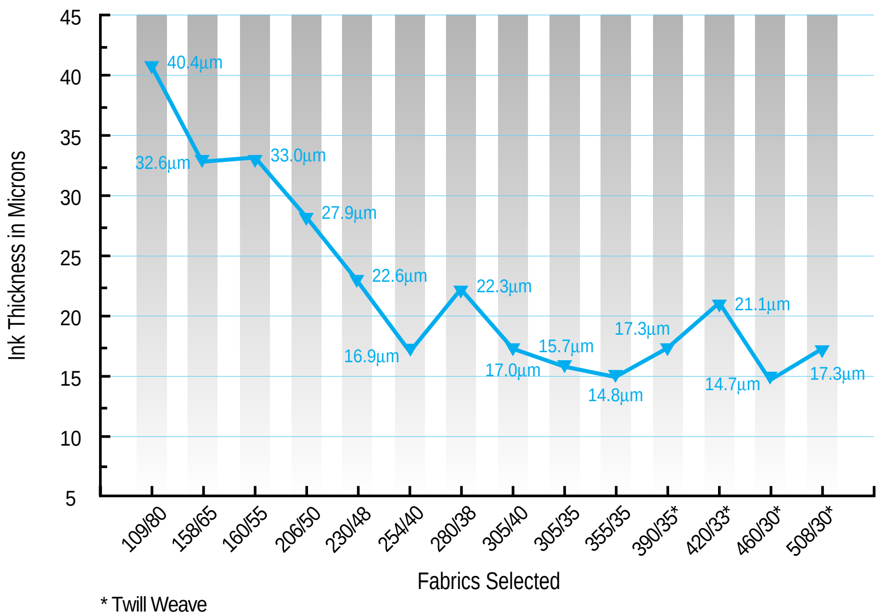
** The fabric thickness measurement may be obtained with a magnetic induction or eddy current measuring instrument using SPTF's calibration procedure for mesh. Without proper calibration, measurements on fabric from these instruments will be inaccurate. This procedure is listed in SPTF's research report Physical Changes in Polyester Mesh During Tensioning.*

Results from this formula have only been confirmed experimentally for a multi-purpose UV ink. Other inks may produce different deposits with these same meshes. In addition, the substrate has a big effect on the resulting deposit and may also change the results. Aside from these qualifications, SPTF's formula has proven to be significantly more accurate in predicting deposit than other formulas currently used in industry.

When using screen printing to create ink samples for color matching applications, it will be necessary to do some preliminary testing. Experimentation is needed to determine what ink thicknesses are produced from different mesh counts under standard conditions on the lab proofing press. Just as

Figure 26

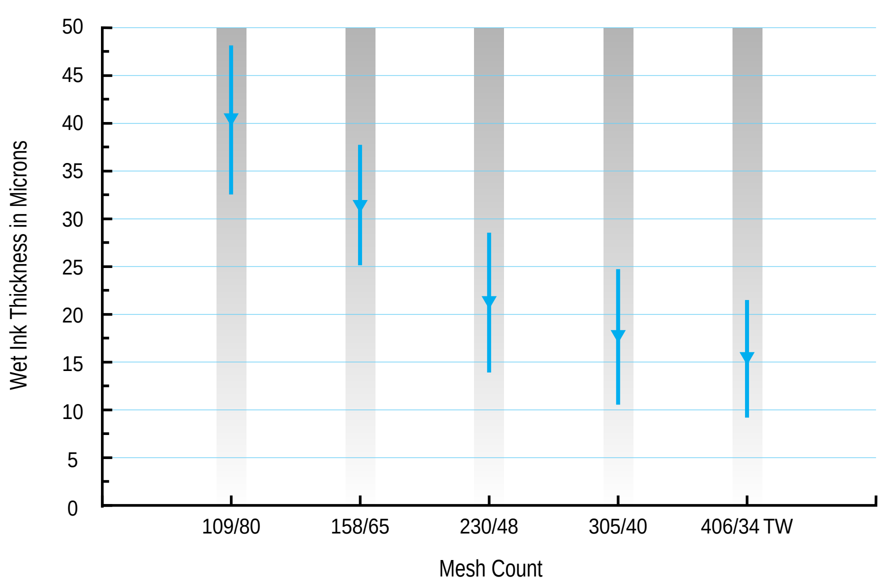
Wet Ink Deposit Averages From Multi-Purpose UV Ink



Actual wet ink deposit is not directly related to mesh count as previously thought.

Figure 27

Hand Screen Printing
Average Plus and Minus 3 Sigma
Multi-Purpose UV Ink Printed on Ground Glass



	109/80	158/65	230/48	305/40	406/34TW
Average	39.84	30.92	20.86	17.22	14.92
Standard Deviation	2.55	2.01	2.39	2.29	1.97

Hand screen printed ink deposits exhibit consistent process spreads for five different mesh counts.

with the fixed open gate device, the ink deposit that will be manufactured on the production press will also have to be determined using the appropriate substrate, mesh and ink. With this in hand, a mesh should be selected based on the results from the lab press that will simulate the thickness produced on the press.

SPTF Research Results

SPTF has done a tremendous amount of testing on the consistency and repeatability of ink deposits produced in the screen printing process. Much of this research has been published in SPTF's report entitled *"Polyester Mesh Capability Study with UV Inks."* The reader is encouraged to obtain a copy of this report for further information in this area.

As with the other two ink deposition methods, we will examine screen printing in the areas of accuracy, repeatability and reproducibility with the results of SPTF's research. Let us first analyze **Figure 27** where five different mesh counts were hand printed on a ground glass substrate with a multipurpose UV ink. Of particular interest in this graph is the standard deviation and corresponding process spread (based on 5 samples and 50 data points) for each of the screens. While the process spread is not exceptionally small, it is surprisingly tight and consistent across the board when considering these samples were manually screen printed. It is understandable that extra variation is present due to operator inconsistencies in hand printing.

In **Figures 28 and 29** we can compare the ink deposit results of mesh that was printed by hand and with a computer controlled mesh with the same ink and substrate. Both graphs depict the averages (triangles) of five different print samples and their corresponding process spreads (vertical lines representing plus and minus three standard deviations). The hand printed deposit **(Figure 28)** produced an average of 17.22 microns and a standard deviation of 2.29 microns. The same mesh on the computer controlled press **(Figure 29)** deposited a nearly identical thickness of 16.98 microns but had a much lower standard deviation of 1.25 microns.

Notice that in both cases the individual sample averages are almost identical to the overall deposit average represented by the dotted line, indicating a high repeatability and accuracy rating for screen printing by hand or press. The similarity between the two overall deposit averages shows that screen printing is highly reproducible with the same ink and substrate even though one was printed by hand and one with a computer controlled press. The benefit with the computer controlled press is that the variation in the deposit thickness is greatly reduced, and the process spread tighter due to the control of press variables.

In looking at another comparison with the same mesh count, **Figures 30 and 31** will allow us to make two additional points. The graph in **Figure 30** is again of a 305/40 mesh that has been hand printed with the same multipurpose UV ink, this time on a 7" x 11" ceramic substrate flat to 0.75 microns. The average is consistent for all five samples, but compared to **Figure 28** it deposited a significantly higher ink thickness. This is an example of how much a substrate change can make a difference in ink deposit. Also observe that the standard deviation is much less than in our previous examples. Again, this is a result of the substrate's smoothness and uniformity. The substrates in this case caused major differences in both thickness and process spread suggesting that it is extremely influential to the resulting ink thickness.

The same mesh was printed on the ceramic substrate with a small semi-automatic press like the one pictured in **Figure 25.** The results **(Figure 31)** show the same ink thickness as the hand printed screen

Figure 28

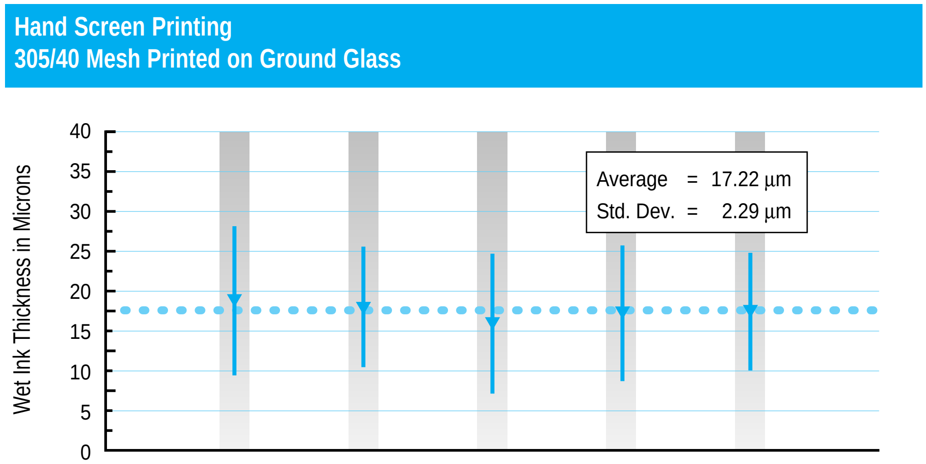


Figure 29

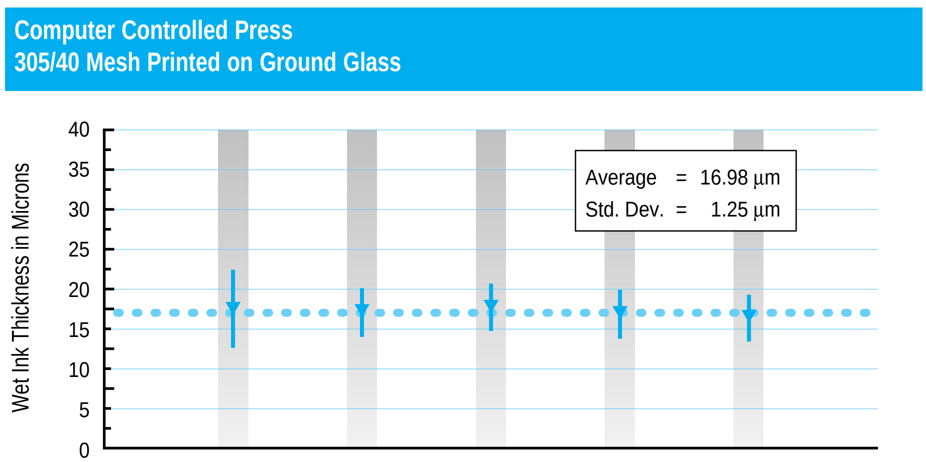


Figure 28 and 29: Comparisons of ink deposits from the same mesh printed by hand and a computer controlled press show that the ink thickness does not change but the variation or uniformity of the deposit decreased with the controlled press.

to within one micron, but with no improvement in standard deviation. It is apparent that the ceramic substrate is primarily responsible for the uniformity of the deposit.

As these and other SPTF findings indicate, screen printing is an inherently predictable and consistent coating and deposition method. The obvious benefit of using screen printing as a sampling method is improved correlation between the sample and printed piece. By using the screen printing process to produce the sample, most of the characteristics of the production print are automatically present in the sample. Therefore, screen printing is an excellent method for sampling ink in color matching as it adds characteristics to the sample unique to the screen printing process that the other methods do not.

Using screen printing as an ink sampling technique is by no means easier than the fixed open gate device. Both require the printer to determine the press printed deposit thickness, and both methods demand that testing be done to determine ink thickness characteristic curves. Proper conditions can then be selected when making an ink sample to a specific thickness.

Figure 30

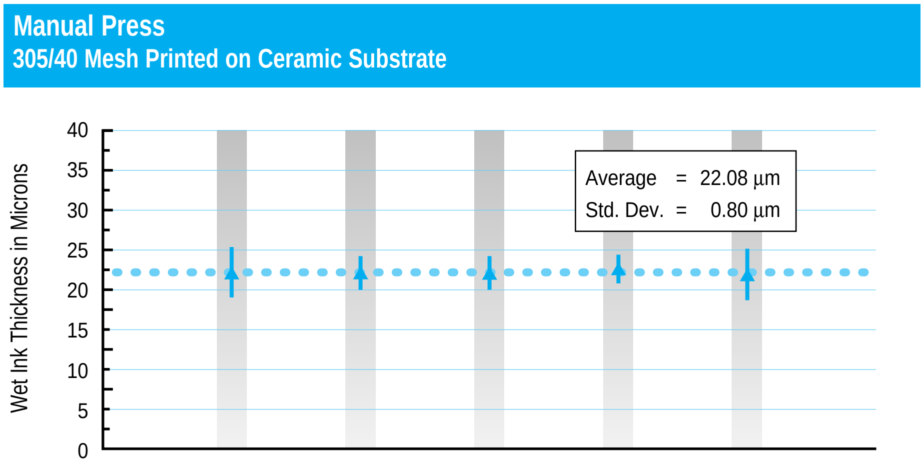
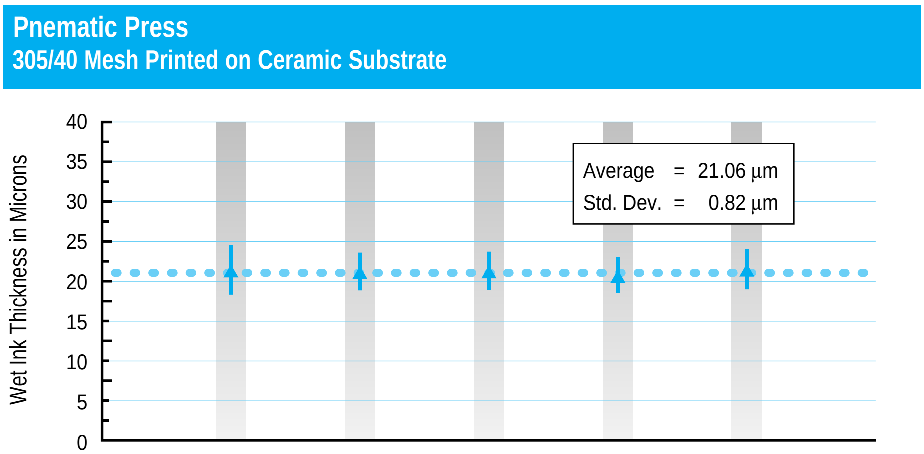


Figure 31



Figures 30 and 31: Ink deposits were made from the same mesh printed manually and on a computer controlled press on a ceramic substrate flat to .75 microns. Both sets of samples have very tight process spreads due, and have significantly higher deposit thicknesses than the same mesh printed on a ground glass substrate (Figures 28 and 29). Both of these results can be linked to the ceramic substrate.

Recommendations

To help clarify which ink sampling method is the most desirable in terms of color matching applications, the SPTF is presenting the following recommendations.

1. **Screen Printing Using a Semi-Automatic Press –** This method offers the most control for creating ink samples using the screen printing process, and is the best option for simulating the characteristics of the production print.
2. **Fixed Open Gate Device Using an Automated Draw Down System –** The fixed open gate is the second best choice. Use of automation with this device makes it easier to set up specific conditions of speed and pressure. With this type of standardization, the operator variation is minimized, and training is simplified. The fixed open gate is easier to create samples with than screen printing, but lacks the ability to fully simulate a screen printed deposit.
3. **Fixed Open Gate Device Manually Operated –** The third choice is the open gate or blade that is drawn down by hand. The lack of automation makes this a less desirable choice than option two. This is however the least expensive of the four, and success can be achieved by standardizing procedures and conditions as much as possible.
4. **Screen Printing Using a Manually Operated Press –** Hand screen printing is the final option for ink sample creation. The lack of automation will cause this to have greater variation than the first three options. However, with proper standard conditions and procedures this method can be used very effectively for this application.

One last word about the wire wound draw down bars is an order. These bars are not recommended to be used for any screen printing ink sampling application, including color matching. If the printer is currently relying on this type of system to produce ink samples, serious consideration should be given to changing over to one of the four methods listed above.

With any of these four options, it is essential that they be used according to the guidelines presented in this paper. Should these important principles be ignored, accuracy in the results obtained from them will diminish. However, if used properly, the improvements in ink sample precision will lead to greater success in color matching applications.

The listing above is specifically aimed at color matching applications. To perform incoming quality control tests on the ink, the fixed open gate options are the best choices.

Conclusions

Color matching is becoming an increasingly important aspect of the screen printing industry. A greater understanding in this area can only help the printer to make better decisions in less time, ultimately saving money and providing faster turn around times. The information contained in this bulletin is intended to provide some practical guidelines that, when implemented, will improve the printer's speed and accuracy in accomplishing acceptable color matches on their products.

SPTF will continue to publish information on this subject as it becomes available.

References:

Hunter, Richard S., Harold, Richard W. *The Measurement of Appearance*. John Wiley & Sons, 1987.

Hunter Lab. *The Science and Technology of Appearance Measurement*. Reston, Virginia, 1990.

Billmeyer Jr., Fred W., Staltzman, Max. *Principles of Color Technology 2nd Edition*. John Wiley & Sons, 1981.

Note: References to specific brands does not imply any endorsement of products by the Screen Printing Technical Foundation.