# Assessing Perceptual and Physical Aspects of Printed Products By Quantitative and Visual Means

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**Abstract**

The assessment of the quality of printed materials has gone through many stages; from the first printed letters being visible or not visible on the first Guttenberg's presses, through controlling the amount of the ink on the substrate by measuring the density of the patches, then assessing color agreement by visual means and later introducing devices that could measure the color coordinates and color differences, all the way to sending digital files along the workflow and confidently reporting only the numbers without ever looking at the color at all. The ways colorimetric appearance is judged nowadays has been studied in great details for couple of centuries now and graphic arts industry implemented successfully these standards and processes.

In this paper, we introduced methods that explain how to capture the visual impression of the studied effect, for example brilliance of metallic inks, and how to investigate ways to quantitatively describe the studied appearance. The study also describes the development of the visual scale for the effects, correlating the scale with instrumental measurements and the development of an equation that relates instrumental measurements and the visual judgments.

## Introduction

Many measurements in the paper and printing industry still have a physical or perceptual aspect of the product that everyone recognizes but no one really understands. Typical attributes in this category emerge especially in the packaging industry where effects play very significant roles in grabbing consumers' attention. Examples of these characteristics, such as metallic or mirror-like effect, whiteness or brightness, opacity or translucency, can be found all around us.

Sun Chemical Corporation

This paper uses the visual assessment of metallic prints and a Brilliance index as an example and demonstrates how this methodology can be extended to apply other important factors including the whiteness or brightness of a paper substrate or the opacity of an ink layer printed over a clear substrate. In all of these cases, objective measurement systems are commonly applied but metrological scales have no known relationship to the perceptibility or acceptability of the appearance quality of the print.

Various experimental scales in this study were defined and analyzed using standard psychometric methods found in Peter Engeldrum's *Psychometric Scaling: A Toolkit for Imaging Systems Development* textbook (Engeldrum, 2000) and Robert T. Ross's *Optimum Orders for the Presentation of Pairs in the Method of Paired Comparisons* book (Ross, 1934). Examples of the work are given in the area of assessment of Brilliance effect in metallic prints and illuminant specific Whiteness values in printing substrates.

## Theory on Appearance of Materials

Packaging printing needs a way to quantitatively describe the visual effect of attributes of inks. The CIELAB, ΔE, Chroma, Color Strength are well established functions for analysis of appearance attributes of a graphic art reproduction. A methodology that allows to visually quantify a less frequently used appearance attributes such as, "least visually apparent", "moderately significant", "very visible" was examined.

Some specialty printing inks are using effect pigments for security (anti-forgery), commercial printing and packaging applications. Nowadays, Vacuum Metalized Pigments (VMP) inks are being used to replace foil and metallized board or film substrates, all of which are fairly expensive. VMP pigmented inks are used to print only the desired fractional area of the package with metal-appearance layers and the rest of the package may be coated white or colored with lower cost inks. Gonioapparent materials change appearance with a change in the illuminating and/or viewing angles. Gonioappearance in printing results from coloring the material with effect pigments, e.g., metal flakes, mica-based interference pigments and/or interference pigments based on other technology. One or several of the attributes of color (lightness, chroma and hue) can change depending upon the particular effect pigments used in the material. Materials which contain only metal-flake pigments predominantly exhibit changes in lightness, and those changes occur only when the viewing angle changes.

There are three types of metal flakes commonly used in metallic inks and are shown in the Figure 1. Cornflake metal flakes, shown in Figure 1a, produce the non-mirror-like to low mirror-like prints that appear to have low brilliance. Silver dollar flakes, shown in Figure 1b, produce medium mirror-like prints that appear to have medium brilliance. Vacuum metalized pigments (VMP), shown in Figure 1c, can produce high mirror-like prints with high brilliance.

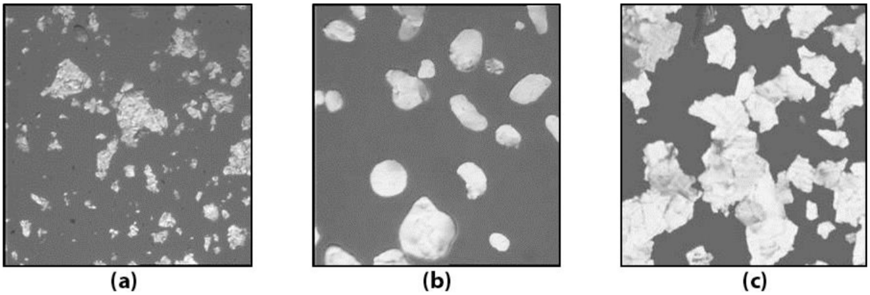


***Figure 1:*** *Three types of metallic flake pigments use in packaging printing inks. (a) "cornflake" pigments, (b) "silver dollar" pigments and (c) vacuum metalized pigments.*

Depending upon the substrate and the type of metal flakes used in the ink, flexo printed packaging goes from appearing from non-mirror-like to mirror-like. The mirror-like prints vary in their haze and distinctness of image while the non-mirror-like prints have a flop-like aspect to their appearance as you go from the near aspecular angle to the far angle. Since gloss seems to play a big role in the metallic percept of printed materials there may be gloss related measurements that may correlate to brilliance. Luster, a type of gloss, has been cited as a possibility but it has a specific technical definition in the literature. ASTM E284 (ASTM, 2005) defines luster as the appearance characteristic of a surface that reflects more in some directions than it does in other directions, but not of such high gloss as to form clear mirror images. That definition does not apply to the experience of consumers looking at a flexo printed package. The term Brilliance was adopted here to describe the appearance of metallic ink prints.

## Instrumentation for Characterizing Metallic Inks and Coatings

Spectrophotometers and multiangle spectrophotometers on the market today essentially measure the reflectance factor of a material rather than its reflectance. While we often refer to this quantity as the reflectance, it is not. Reflectance factor is the reflectance of a material compared to the reflectance of the perfect reflecting diffuser under the same geometric and spectral conditions. This is a particularly important distinction when making measurements near the specular angle.

By definition, the perfect reflecting diffuser diffuses all of the incident light. A mirror will reflect all of the incident light at the specular angle. This concept is illustrated in Figure 2. In the figure, the circle represents the reflectance of the perfect diffuser. The intensity of the incident light is spread throughout the circle. The arrow leaving the circle at the specular reflection angle represents the reflectance of a mirror. The intensity of the mirror's reflectance equals the intensity of the incident light.

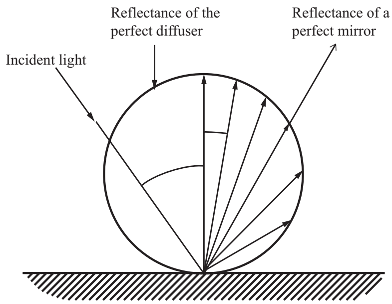


***Figure 2.*** *Reflectance of a Perfect Diffuser and a Perfect Mirror*

Traditional bidirectional spectrophotometers (45°:0° and 0°:45°) have only one illumination angle at either 45° or 0° and one viewing angle at either 0° or 45°. These geometries do only a fair job of controlling packaging colors printed on metallic foil or inks containing metal flakes and thus we eliminated them from the study.

The first instrument used in the study was an integrating sphere that uses a gas filled tungsten lamp to illuminate the sphere and a receiver that uses blue enhanced photodiodes. The specimen efflux is received at 8° from the perpendicular and thus the specular or gloss angle is also 8° from perpendicular. Figure 3 below is the schematic of an integrating sphere instrument.

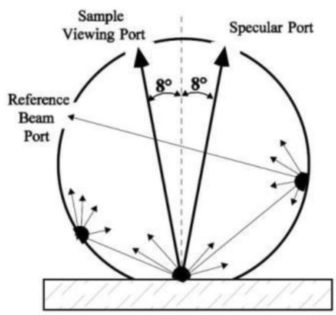


***Figure 3.*** *Schematic of an Integrating Sphere Instrument*

The multiangle instrument used was a bi-directional instrument with two illuminating angles and 10 viewing angles. The only investigated angles were the 45° illumination and 3 aspecular viewing angles (15°, 45° and 75°). The light source is a gas filled tungsten lamp.

Also considered was a possibility that a measurement related to the specular reflectance such as gloss or haze is sufficient to determine the brilliance of a metallic ink. To test this idea, we used two instruments to measure gloss related quantities. The three angle gloss meter can measure both gloss and the specular reflectance (directly proportional to gloss) at 20º, 60º and 85º. Gloss is associated with the capacity of a surface to reflect more light in directions close to the specular than in others. In a gloss meter the axis of the incident beam shall be at one of the specified angles from the perpendicular to the specimen surface. The axis of the receptor shall be at the mirror reflection of the axis of the incident beam.

The last instrument included in the study was an abridged goniophotometer that measures not only 20°/60°/85° gloss values but several gloss related functions – Haze, RIQ (related to distinctness of image gloss) and RSpec. RSpec is the peak reflectance measured over a very narrow angle in the specular direction. The specular direction for an RSpec measurement is 20º with the receiver having a window (aperture) width of 0.0991º. RSpec is very sensitive to any surface texture. Waviness or rippling on a surface acts as a concave or convex reflector deflecting light around the specular angle. When RSpec is equal to the gloss the surface is smooth, RSpec drops as texture becomes apparent.

## Experimental

*Sample Preparation and Measurements*

For the visual experiments we defined multiple different series designed as Rank Order method and Direct Interval Scaling experiment as defined in Peter Engeldrum's book. In the first three experiments the observer was asked to rank the samples in order, from best to worst, along an attribute defined by the instructions, such as metallic effect, shininess or brilliance. In the fourth experiment, we followed the Ruler method for interval scaling by placing anchor specimens near the ruler's low and high end and asking the observers to place the judging specimens on the ruler, varying the distance according to the amount of the "ness" effect as compared with the anchor specimens. The results of the Interval Scale experiment will not be discussed in this paper. Since we had evidence that the SPI correlated to the percept of brilliance, we selected the series of specimens based on their SPI.

The experimental series were:
- Series B – metallic specimen on board with and without primer
- Series L – metallic specimen on controlled chart
- Series M – metallic specimen on mixed substrates
- Series I – metallic specimen for internal scaling experiment

All the selected samples were cut precisely to same dimensions and mounted onto a black backing material with flaps for better handling. The visual experiment was run in a special light booth with matte black metal inserts under a D50 fluorescent lamp. This booth does not have a diffuser between the lamps and the floor of the booth so the lamps are well defined when they are viewed using a mirror-like surface. A plastic mesh was taped to the top of the booth below the lamps, Figure 4, as a distinctness of image target.

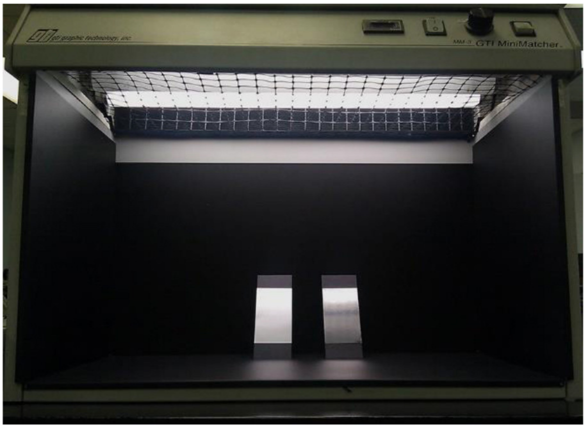


***Figure 4.*** *Light Booth with Matte Black Metal Inserts and Mesh.*

### *Visual Experiment Set Up*

Observers were asked to order samples of metallic ink from left to right in order of Brilliance, with the least brilliant on the left and the most brilliant on the right. The initial spread of the samples was random as shown in Figure 5. Observers were allowed to pick up the samples and view them at different angles. The total number of valid observations for each series was 51. We asked five people to repeat the experiments so that five out of all observations were repeats.

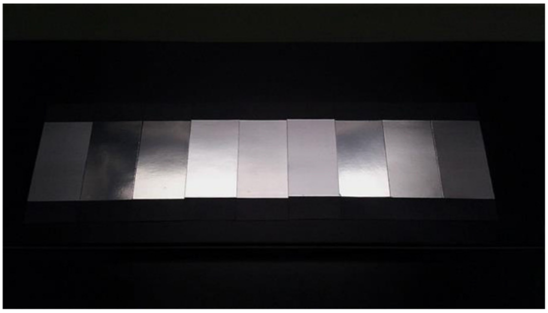

***Figure 5:*** *Rank Order Specimens.*

For the interval scale experiment, a "brilliance" ruler with two anchor specimens was placed in the booth, Figure 6. The observers were given a total of 10 specimens one at a time. They were asked to determine where on the brilliance ruler the brilliance of the sample belongs. Observers were allowed to pick up the specimens and anchors and view them at different angles. Figure 7 shows an observer making a judgment.

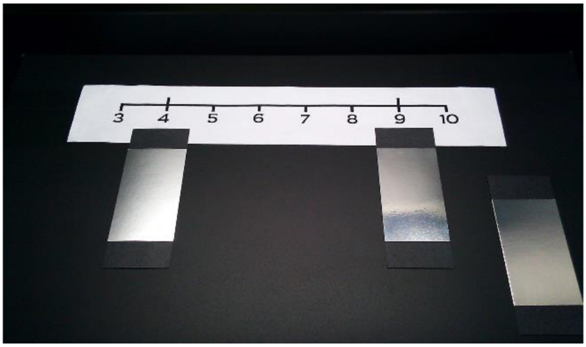


***Figure 6:*** *Interval Scale Ruler with Anchors and a Specimen.*

***Figure 7:*** *Observer Judging Specimens.*

All of the samples that were included in the visual experiment were measured for various characteristics. Measurements of the samples were made using a BYK micro-TRI-gloss three angle gloss meter, an X-Rite MA98 Portable Multi-Angle Spectrophotometer, an X-Rite SP64 Portable Sphere Spectrophotometer and a Rhopoint IQ (Goniophotometer) 20°/60°/85°.

- Specular reflectance values were derived from the gloss data taken at different angles, 20°, 60° and 85° on BYK micro-TRI-gloss.
- Tristimulus values for Illuminant C and the 2º Standard Observer were measured using three different geometries on MA98.
- SP64 tristimulus values for Illuminant C and the 2º Standard Observer combination with specular component included and excluded were also recorded.
- Haze, Log Haze, DOI/RIQ and RSPEC values were collected from the Rhopoint IQ instrument. All the data was saved and submitted to further analysis.

Eckart has reported some success using integrating sphere instruments to control metallic inks. A Specular Index, SPI, based on measurements of the specular included (SPIN) and specular excluded (SPEX) reflectance has been thought to correlate with the percept of brilliance. In this case, the SPIN readings include both diffuse and specular port readings while the SPEX readings contain only the diffuse port readings. The normalized difference of the two sets of readings we have termed the Specular Index or SPI.

$$SPI = 100 * \left(\frac{Y_{SPIN} - Y_{SPEX}}{Y_{SPIN}}\right)$$

in which $Y_{SPIN}$ is the luminance factor of the specimen's specular included measurement and $Y_{SPEX}$ is the luminance factor of the specimen's specular excluded measurement. The index, thus, reports the percent of the total reflectance that passes through the specular port.

## Analysis

The four visual experiments provided scales for how people see Brilliance. The next step was to correlate instrumental measurement data to determine what measurements can be used as the basis of a Brilliance Index. The Specular Index, SPI, based on specular included and specular excluded measurements has been thought to correlate with the percept of brilliance. This maybe because the specular included and specular excluded measurements mimic how observers evaluate brilliance in the laboratory.

The Series B and the Series L visual experiments produced a rank order ordinal scale of average rank, Figure 8. Series M contained on multiple substrates and will be discussed later. Because of the statistically significant high values of Kendall's Coefficient of Concordance (W's of 0.97 and 0.95 for Series L and Series B, respectively), we can be certain that our observers judged differences in brilliance in the "same" way when the inks were on the same substrate. The resulting associations showed a satisfactory linear fit to a linear statistical model and agreement between observers when asked to judge Brilliance of the printed material.

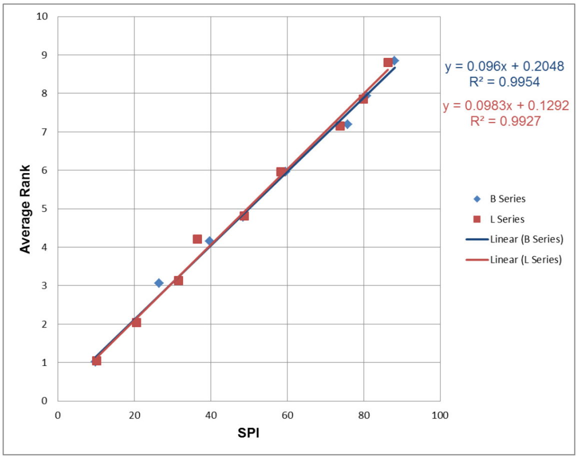


***Figure 8:*** *Plot of the Average Visual Ranking against Instrumental Specular Index value.*

In the next step we tried to verify that the visual data collected in the previous study that was based on the SPI values were not biased and were typical of the visual assessment of specular reflectance and to determine if the goniometer instrument readings could be transformed into the same scale as the visual evaluations based on the responses of Specular reflectance gathered, Figure 9. For this part of the experiment, the abdridged goniometer was used and RSpec values were collected from the samples.

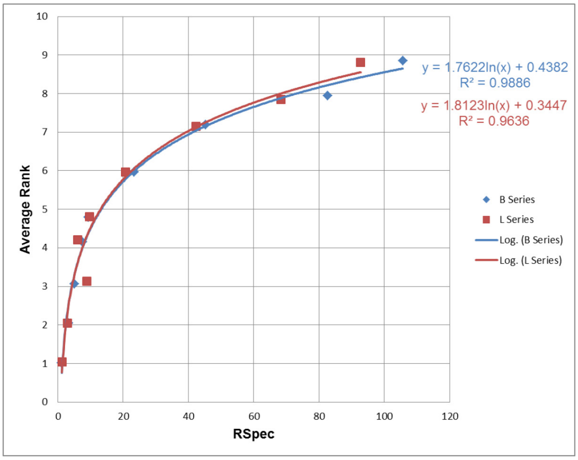


***Figure 9.*** *RSpec Correlations for Series B and Series L.*

From the collected data we have been able to derive a mathematical scale of specular reflectance from the abridged goniometer that agrees with the SPI index for the Brilliance of a print containing metallic ink. We obtained the results shown in Figure 10. In this figure, we compare the SPI scale with the scale based on 17.8 Ln(RSpec) + 4.1. The linear fit to the visual data between the SPI index and the Ln(RSpec) index is statistically identical.

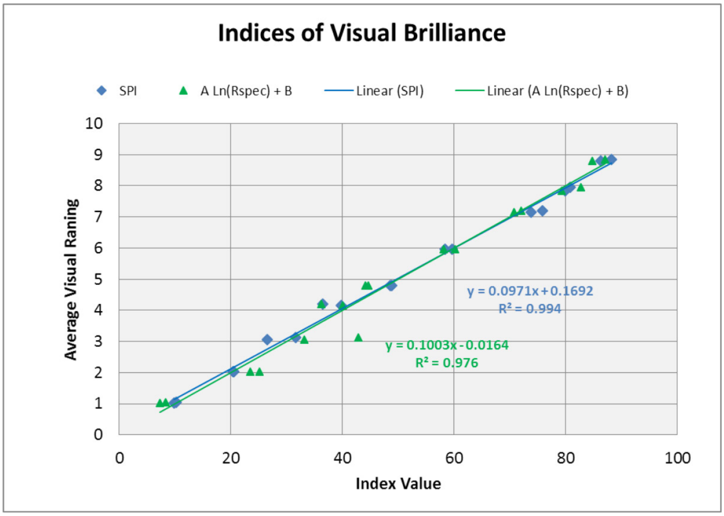


***Figure 10:*** *Comparison of the SPI Index and the Logarithm of Luminous Reflectance.*

Series M was developed to provide information about the effect of the substrate on metallic inks. Four of the same inks proofed on two different substrates were included in this series. Figure 11 below is a plot of the rank order for all of the 10 samples that made up Series M compared to the SPI.

Once we separated the data for M series by substrates, the resulting plots suggested the effect of the substrate on the perceived level of Brilliance, Figure 12. We compared specimen pairs in an attempt to determine why the same inks proofed on one substrate appeared to be less brilliant than the other and have a different surface texture. The difference in structure becomes more evident as they go from low brilliance to high brilliance. The proofs on one substrate looked smoother and more like a foil whereas the proofs on the other looked more sparkly.

The sparkly appearance seems to lead to the perception of higher brilliance. The differences in rank order and SPI may be within the noise of the experiment but affect seems to be consistent. Care must be taken when comparing a numerical Brilliance Index to any particular substrate. Figure 13 shows this affect using the two specimens with the highest visual brilliance.

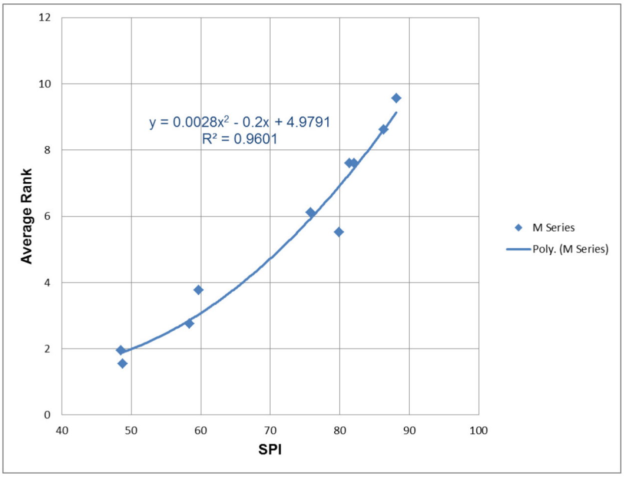


***Figure 11:*** *Correlation of SPI with Average Rank for Series M.*

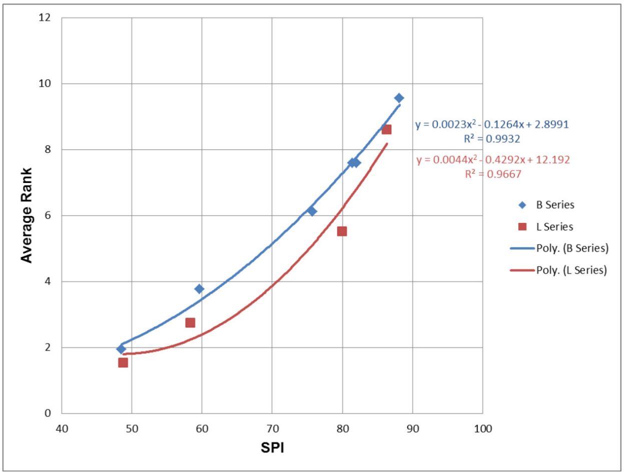


***Figure 12:*** *Effect of Substrate on Rank Order*

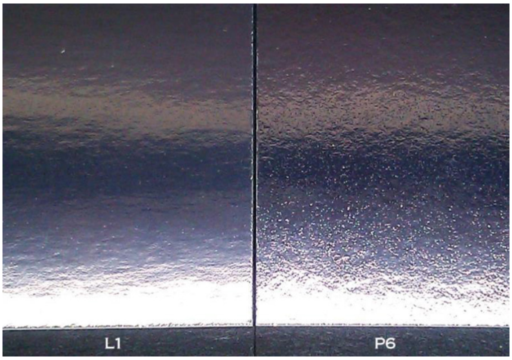


***Figure 13:*** *Specimen of the Same Ink Prepared on Two Different Substrates.*

The 20º Specular Reflectance appear to be more useful for specimens having high brilliance – a 20º Specular Reflectance greater than approximately 5 (about 50 SPI units). Haze and Log Haze appear to be more useful for specimens having lower brilliance – a Haze value of approximately less than 200 (about 50 SPI units) or a Log Haze value of approximately less than 1300 (about 50 SPI units). When we compared measurements made using the MA98 Multi-Angle Spectrophotometer to the visual scales we did not get satisfactory correlations. We attribute this to the thinness of an ink film compared to a paint film and the way the metal flakes orient within the ink film.

*Whiteness Implementation*

For the assessment of the Whiteness or Brightness on various printing substrates that included samples with and without optical brighteners, paired comparison analysis was applied. The same approach as in the work on Brilliance Index was employed. The observers were required to perform two separate visual tasks, similar to that described by Grum and consistent with the recommendations of Swendholt and Grum (Swendholt, 1978).

The specimens were first ranked by the observer from lowest whiteness to highest whiteness, Figure 14. Next the observers re-examined the specimens and assigned a magnitude using a close approximation to the Perfect Reflecting Diffuser as the scale reference. The specimens were measured for total radiance factor utilizing a spectrodensitometer with ISO 13655 (ISO 13655, 2009) compliant, geometry (45°:0°) and with a source with a very good fit to CIE D50 as described in ISO 3664 and as required by ISO 13655 for the measurement mode M1.

***Figure 14:*** *Specimen of the different Whiteness levels.*

The equation for Whiteness was encoded as given in the Ganz paper where he indicated that the coefficients were developed only for CIE D65 and the 1964 Standard Observer (Ganz, 1981). ASTM E313 assumes that the D65/10° coefficients could be applied to other standard illuminants and observers (ASTM E313, 2010).

$$W = Y + 800\,(x_n - x) + 1700\,(y_n - y) \qquad (1)$$

New coefficients were determined by multiple linear regression to maximize the correlation coefficient between the computed Whiteness values and the visual ranking of the percept of Whiteness. The data sets, the optically brightened papers and the non-optically brightened papers, produced the same set of coefficients for the equation that best fit the visual rankings (1, 900, 10) for CIE D50 and the 1931 2° color-matching functions with an R2 of greater than 0.98.

$$W = Y + 900\,(x_n - x) + 10\,(y_n - y) \qquad (2)$$

Figure 15 shows plots of the Visual Ranking versus the Visual Magnitude. The scaled magnitudes were in good agreement with the rank orders. It was believed that this data set was highly significant with excellent agreement among the observers.

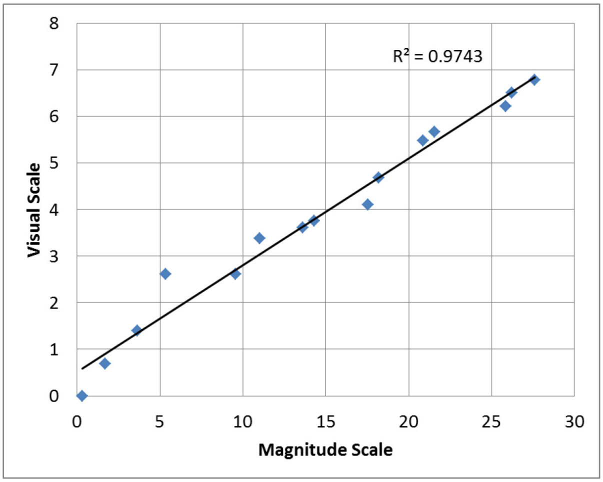


***Fig. 15:*** *Comparison of the visual ranking to the magnitude score.*

## Conclusions

The visual scale of a specific non-colorimetric attribute is not such an easy percept to capture as these attributes are aspects of advanced colorimetry and appearance. Thus we endeavored on the path of examining the best ways of assessing these correlations. Extensive experimental exercises were conducted in order to successfully capture visual assessments of the special attributes and correlations were derived for these. The data collected in this study appears to be fully consistent with all of the data reported in the literature and yet, it does not show the level of correlation to visual scaling that is reported in the research papers.

As graphic arts reproduction process progresses from an art form to an engineering discipline, it will be necessary in the future to capture the visual significance of these quality parameters so that rational aims and tolerances can be assigned and controlled.

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