Color Matching to an Electronic Standard:
Why We Should Use Reflectance Data Over Absolute L*, a*, b* Values
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January 2019

It has become routine for customers to ask if we can formulate a color match to electronic absolute *L, *a, *b values in lieu of sending us a physical color target to measure with our own spectrophotometer. We've all become accustomed to how quickly and easily information is communicated electronically across distances and companies. Having to ship a physical color standard like a paint chip, molded part, or color chart seems outdated when information can be transmitted almost instantaneously. At first glance this looks like a good idea. No boxing and shipping or waiting for transit time to our labs. If a customer is offering *L, *a, *b values it means they have already measured the color target. Why incur shipping cost and lost time just to repeat the process? While the spirit of the idea is sound, this paper illustrates why the practice of using *L, *a, *b values is less than reliable.

The quick explanation is that *L, *a, and *b values are too mathematically dilute to properly generate a trustworthy match. Absolute L*, a*, b* values are generated as a mathematical product which only includes one light source. Think of these values like a speed dial code on your phone being a shorthand version of the full phone number stored elsewhere. *L, *a, *b is a shorthand version derived from a full set of reflectance data collected by the spectrophotometer and stored elsewhere within the software. Since we are incapable of 'un-calculating' the values back into the raw spectral data there is no way to compare across multiple light sources. This leaves any suggested color match vulnerable to metamerism, or the condition of two colors appearing the same under one light source and differing under another light source.

I suspect users of color software resort to *L, *a, *b values because they are conveniently visible. Most spectrophotometer color software displays these values at the top of each color difference report. While these numbers are all that is needed when determining color difference between a target and batch, they don't necessarily represent the full characterization of a color. Perhaps less convenient but far more effective is the spectral percent reflectance data that is expressed as percent reflectance in 10 nm increments across the visible light spectrum. This information may not be readily evident but should be retrievable from most brands of color software. This information normally consists of thirty-one data points and is often printable or can be exported as a text file. Being able to find and transmit the raw reflectance data is as good as having your colorant supplier measure a target themselves.

For those looking for a more in-depth explanation, the following paragraphs offer additional detail about how spectrophotometric data is collected, processed, and used to predict color match formulas. Many of these topics are easily worth full articles on their own and the overview below is at best an introduction.

In basic terms, a spectrophotometer consists of a light source, a measurement port, and a detector. Instrument manufacturers are cringing at my reduction of their technology to such basic elements but for our purposes this should suffice. The machine operates by exposing a physical part such as a paint chip, swatch, etc. to a controlled light source through the measurement port. Some of this light is absorbed by the part, which is what we recognize as the hue we see. Some of this light is scattered, which means it bounces off the part surface at different angles. Some light is reflected at an angle equal to the incident angle of the light source and referred to as the specular component. The specular component is normally excluded for color measurement because the surface profile of part can affect the perceived appearance. Excluding the specular component removes the appearance effect.

The scattered light is measured by the instrument's detector and passed through a beam splitter to separate the reflected light into 10 nanometer increments across the visible energy spectrum of 400-700 nanometers. The resulting data consists of 31 points of percent reflectance that fully represents the characteristics of a given color (Figure 1). A spectral reflectance curve is the plotted representation of this data in visual form (Figure 2). Once this data is collected the spectrophotometer's work is done and it is the software's turn to go to work.

% Reflectance 10nm Hor						
Standard: %R **EHC50009 STD**			%R / %T Plot		K/S (Absorb.)	
400-450 nm	13.62	13.89	13.74	13.47	13.16	12.74
460-510 nm	12.23	11.85	11.38	11.05	10.72	10.29
520-570 nm	10.04	9.83	9.73	9.58	9.59	10.11
580-630 nm	13.72	24.47	42.89	61.44	72.30	77.86
640-690 nm	80.15	81.39	81.87	81.92	81.84	81.33
700 nm	80.38					

Figure 1: Reflectance data

By nature, those who typically solicit American Colors for color matching help do not have the capability to do so in-house. This likely means they are more familiar with only measuring color difference in terms of Delta values. While absolute L*, a*, b* values are necessary components in color difference calculations, they are not necessarily a part of formulating color match predictions. Color matching software utilizes variations of the Kubelka-Munk equation to determine which combination of pigments at specific concentrations combine to replicate the actual reflectance data of the color target. Utilizing the full reflectance data

allows for calculations against multiple light sources to avoid metamerism. Color difference calculations can be applied downstream to numerically estimate the potential color difference in the predicted formulations.
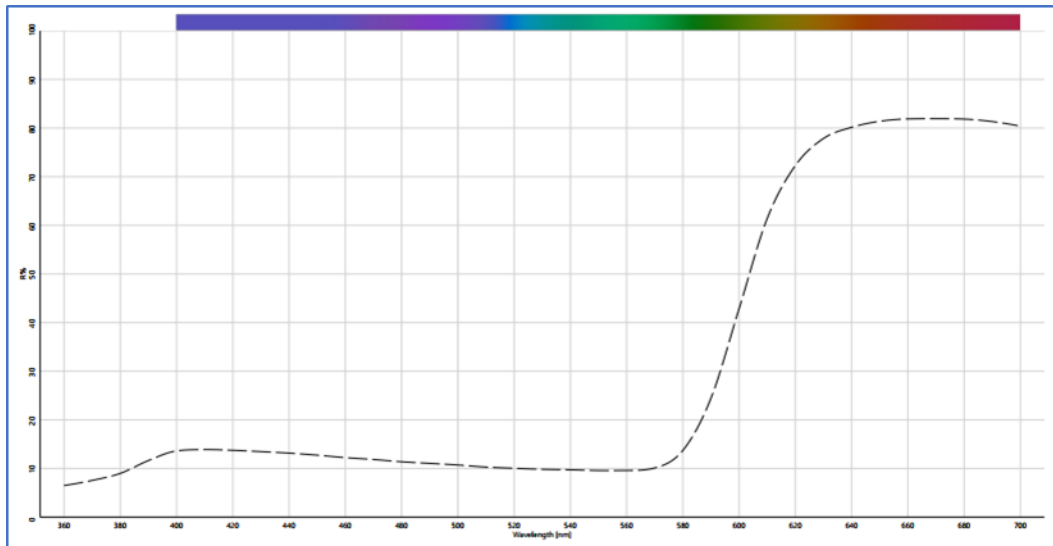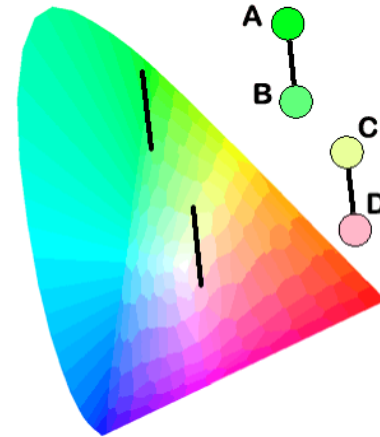

Figure 2: Reflectance curve

Precise calculations are needed in order to eventually determine color difference delta values. The raw reflectance data is multiplied by a mathematical model of a standard illuminant and again multiplied by the CIE Standard Observer. Illuminants and the CIE Standard Observer are well-documented topics and too large to provide more than a brief introduction here. A standard illuminant is a numeric representation of the energy spectrum for what is considered a typical real-world light source. In the industries we serve, they are most typically Daylight (D65), Cool White Fluorescent (CWF), and Incandescent (A10). The CIE Standard Observer is a data set representing average human color vision that was derived from human observation.

The result of all this multiplication are tristimulus values communicated as X, Y, and Z values. These tristimulus values represent each of the three primary color hues (red, green, and blue) and stand as the foundation of the universal color language. A color can defined by its unique set of X, Y, and Z values representing some combination of intensity of the three primary hues. X, Y, and Z are used to calculate *L, *a, and *b values, which in turn become the basis of a linear color system. *L, *a, and *b values are used to determine color difference by application of tolerancing equations like CIE Lab or CMC.

X, Y, and Z is not a linear system like *L, *a, and *b. The benefit of a linear color system like *L, *a, and *b is that in three-dimensional color space, the same magnitude of distance between any set of two colors represents the same magnitude of color difference regardless of hue, Figure 3.

Color tolerancing conventions apply equations to L*, a*, b* values to generate color difference metrics expressed in an opponent system – white being the opposite of black, red of green, and yellow of blue which are all arranged on different axes of three-dimensional color space. The industries American Colors serves typically utilize CIELab or CMC tolerancing. Other systems exist but these systems tend to take precedence. CIELab and CMC fundamentally differ in the weight assigned to lightness and chromaticity. CIELab is a linear tolerancing system, despite human color vision not behaving linearly. It is generally accepted that human vision has a greater tolerance for lightness-darkness difference between two specimens when the hue is very close. The CMC tolerancing system is weighted to accommodate this aspect where CIE Lab does not. Arguments abound for which system is better represents human vision.

As you can see in this gamut chart, A to B is similar to C to D, but perceptually, A and B are almost the same color whereas C and D are very different.

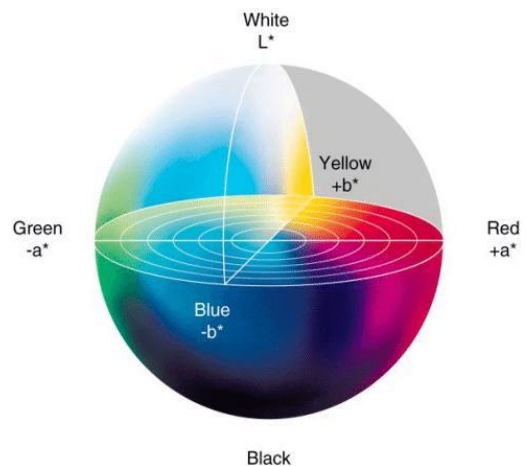**Figure 3:** XYZ chromaticity plot

Absolute *L, *a, and *b values are critical to the calculation of color difference, regardless of the tolerancing system used. Non-metameric color matching requires more spectral information than can be derived from the absolute values alone. Although less visible, thirty-one-point reflectance data is generally retrievable and offers full functionality to color formulation software.

Figure 4: CIELab color space

Additional Reading

Color Fundamentals Part 1 - http://industrial.datacolor.com/support/wp-content/uploads/2013/01/Color-Fundamentals-Part-I.pdf

Color Fundamentals Part 2 - http://industrial.datacolor.com/support/wp-content/uploads/2013/01/Color-Fundamentals-Part-II.pdf

Metamerism - http://industrial.datacolor.com/support/wp-content/uploads/2013/01/Metamerism.pdf

Color Tolerance Systems - http://industrial.datacolor.com/support/wp-content/uploads/2013/01/ Color-Differences-Tolerances.pdf

Figure 3 is courtesy of http://www.colorbasics.com/CIESystem/