Rite Systems

Colorants for Polymers

Color & the CIELAB System

An Interpretation of the CIELAB System

Color perception has been debated for many years and, as in any evaluation that relies on human senses, the essence of analysis remains subjective. However, with the evolution of computerized color systems and controlled, artificial light sources, a more objective method to differentiate color is available. Currently, there are many excellent software packages that translate detailed, color formulas into mathematical calculations.

CIELAB, discussed here, is a mathematical, color evaluation system. Other systems available include Hunter Lab and FMC II. But the OE system is recognized as the industry standard for artificial color evaluation.

Three Elements Required for Color Description

To perceive color accurately, three elements are required:

- Light Source
- Sample
- Observer

Light Source

Typically, the color industry uses artificial daylight (D65) as the standard light source for color evaluation and color con~ro1. (For our purposes here, we will call it daylight.) As seen in a laboratory light booth, daylight offers a very vivid and detailed source for evaluation.

Manufacturers will use a light source that is industry specific, and daylight is only one of those sources. For example, an automotive manufacturer may employ "horizon light" or "cool white, fluorescent light." Or, a toy manufacturer that displays finished products in stores with cool white, fluorescent bulbs may evaluate color under the same light source in the laboratory.

The color computer's light source is measured by an instrument called a colorimeter or a spectrophotometer. The spectrophotometer contains the D65 light source and various other components required for color analysis. The operator measures a standard color through the lens of the spectrophotometer. The instrument then reports the results to the computer which, in turn, performs a mathematical calculation. The sample color to be evaluated is then analyzed by the same process and compared to the standard.

Sample

The sample is the actual molded part or color chip that is being analyzed against the standard. It is vital that the standard and the sample be molded under the same conditions. This will ensure that the gloss, thickness of the part, temperature stability, and other processing variables remain constant.

If, for example, there is a perceived difference in gloss due to a change in molding conditions, the color control software and artificial light source will perceive the sample as being "off color." And this may jeopardize the integrity of the final product.

Observer

In color evaluation and color control, the instrument used to view the sample is called the observer. The human eye is still the best observer, but in artificial color evaluation we rely on the lens of the spectrophotometer.

CIELAB* Color Space

The International Commission on Illumination (called CIE) completed the first phase of CIELAB in 1931. It initially was developed as an objective, color evaluation method using a light source, a sample, 'and an observer. The original evaluation was called the two-degree observer because it was based on a two-degree field of vision. This method of viewing a sample is equivalent to what the human eye would see from a distance.

In 1965, the Commission made two substantial changes to the CIELAB system by developing the ten-degree observer and defining artificial daylight (D65) as a standard illuminate. The ten-degree field of vision better represents a sample viewed at arm's length. And in 1976, the Commission's last revision of the CIELAB System was called CIE 1976.

The CIELAB system uses tristimulus values which are the artificial interpretations of what the human eye sees. These values are defined as: X (representing the red stimulus of the eye), Y (representing the green stimulus of the eye), and Z (representing the blue stimulus of the eye). The Y tristimulus is also used to represent the lightness of a sample.

Basically, the CIELAB system compares a sample to a standard and makes a numerical determination based on the perceived color difference. In other words, the color difference is given a value and plotted on a chart.

The chart or area that the CIELAB system recognizes is called the "color space" (see Figure 1 below). This theoretical space can be conceptualized as a three-dimensional cylinder with an axis running through the center from top to bottom. However, CIELAB uses a square plane to demonstrate the red/green and yellow/blue axes through the cylinder.

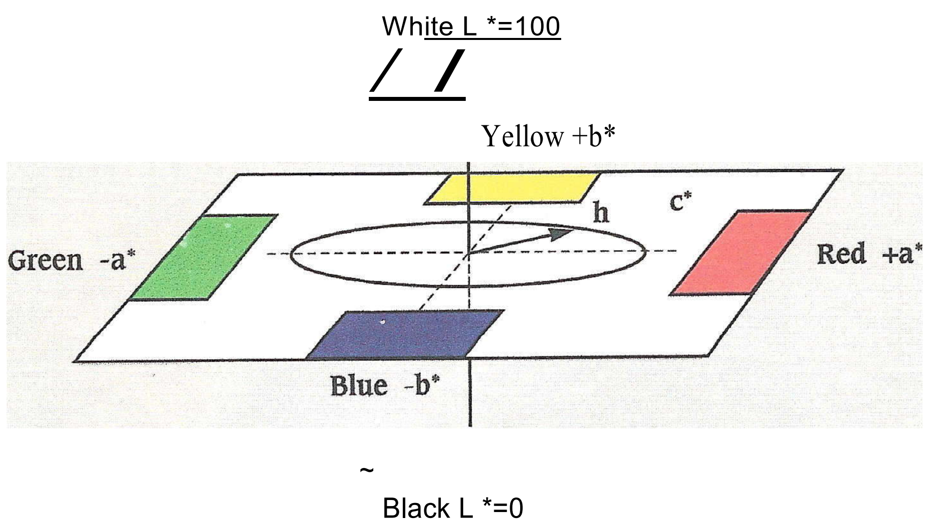
The table at the right shows the CIELAB Color System values which are described in more detail on the following pages.

** The term "CIELAB" combines the commission's abbreviation (CIE) with letters that represent aspects qf color space (LAB) as illustrated in Figure 1.*

CIELAB Color System

Value	Description
L*	Lightness/darkness (0 = Black; 100 = White)
a*	Red shade (if the value is positive) Green shade (if the value is negative)
b*	Yellow shade (if the value is positive) Blue shade (if the value is negative)
DL'	Lighter than standard (if the value is positive) Darker than standard (if the value is negative)
Da*	More red than standard (if the value is positive) More green than standard (if the value is negative)
Db*	More yellow than standard (if the value is positive) More blue than standard (if the value is negative)
DC	More saturated than standard (if the value is positive) Less saturated than standard (if the value is negative)

Figure 1: L*, a*, b* Color Space Chart



CIELAB System

L * Values

The "lightness" of a sample is represented by the symbol "L*" and this value is based on the percent of light reflectance. In the color space chart (Figure 1, page 3), the L* value is the vertical axis running through the center. For this discussion, consider a gray sample that is void of hue so that only its lightness or darkness is relevant.

If the L· value is zero, the sample is black (as shown at the bottom of the chart). If the value is 100, the sample is white (as shown at the top of the chart). Any sample that is void of hue and falls somewhere between 0-100% reflectance will be a variation of gray. If the value is closer to 0%, the sample will be a darker gray. If closer to 100%, it will be a lighter gray.

DL * Values

The Delta L· or "DL·" determines the lightness/darkness difference between a sample and a standard. This is done simply by subtracting the L· value of the standard from the L· value of the sample. If the result of this calculation is a positive number then the sample would be "lighter" than the standard. If negative, the sample would be "darker" than the standard. For example, if the sample reveals an L· value of 43.17 and the standard reveals an L· value of 43.73, the Delta L or DL· value would be -.56 (43.17 - 43.73 = -.56). (See Figure 2, at right.) In other words, the sample is .56 CIELAB units "darker" than the standard. (Note that for all delta calculations, the standard value is always subtracted from the sample value.)

a* Values

The "a·" value refers to the red shade/green shade color difference. This does not necessarily mean that the sample is a red or green color, it only means that it has a red or green shading. Because red and green are opposites (or complementary colors) in the spectrum, a colorist would have to add a green shade to counterbalance the red shade or add a red shade to counterbalance the green shade.

In the color space chart (Figure 1, page 3), the red shade/green shade is represented by a horizontal plane that runs east to west. If the a* value is positive, it would appear in the red region of the color space. If negative, it would appear in the green region. An a* value of zero, means the sample is gray and would appear directly in the center of the red/green plane. Notice that this plane also intersects with the lightness/darkness axis so that the intensity of a color with an a* value of zero is actually determined by its L· value.

Da* Values

The Delta a* or "Da*" value determines the red shade/green shade distinction between the standard and the sample. This is the difference between the a* value of a standard and the a* value of a sample. For example, if the a* value of a sample is -.53 and the a* value of a standard is 1.03, the Da* value would be -1.56 (-.53-1.03 = -1.56). (See Figure 2, below.)

Figure 2: Sample CIELAB Color Analysis

CIELAB Difference
SA V /Spec locI

1) *D65110* deg
2) A /10 deg
3) CWF *110* deg

	Blue Standard					
1		**L***	**a***	**b***	**C***	**h**
2		43.73	1.03	-46.30	46.32	271.27
3		38.37	-14.69	54.65	56.59	254.95
		39.18	2.50	-54.30	272.64	272.64
	Evaluated Sample					
1		43.17	-0.53	-44.78	269.32	269.32
2		37.84	-15.49	-53.22	55.43	253.77
3		38.62	1.23	-52.60	52.62	271.34
	DE*	**DL***	**Da***	**Db***	**DC***	**DH***
1	2.3	-0.56	-1.56	1.52	-1.54	-1.95
2	1.7	-0.53	-0.80	1.43	-1.16	-1.18
3	2.2	-0.56	-1.27	1.70	-1.74	-1.30

Since, in this case, the Da* is a negative, the perceived color difference (as analyzed by the spectrophotometer) would be green to standard. If the Da* value was positive, the color difference would be red to standard.

b* Values

The yellow shade/blue shade value is designated by the letter "b*." Again, these values do not necessarily mean that a sample is yellow or blue in color. It simply means that the sample has yellow or blue shading.

The color space chart (Figure 1, page 3) shows the yellow shade/blue shade variable on the horizontal plane running north to south. If the b* value of a sample is positive (such as 46.30), the sample would appear in the yellow region of the color space. If negative, the sample would appear in the blue region.

Db* Values

The Delta b* or "Db*" value determines the yellow shade/blue shade difference between a standard and a sample by subtracting the b* value of a standard from the b* value of a sample. As in our example on page 4, when the b* value of a sample is -44.78, and the b* value of a standard is -46.30, the Db* value will be 1.52 (-44.78 - (- 46.30) = 1.52). (See Figure 2, page 4.)

Since the Db* value is positive" the perceived color difference (as analyzed by the spectrophotometer) is yellow to standard. If the Db* value is negative, the color difference would be blue to standard.

Note in the color space (Figure 1, page 3) that axis b* runs perpendicular to axis a* on the same horizontal plane. This means that every color sample being evaluated has both a red/green shade (a*) and a yellow/blue shade (b*). It is impossible to have one without the other.

C* Values

A human observer may analyze a color sample as being "more intense" or having "more color" than the standard. In this case, the sample could be described as being saturated with color. This aspect of the color is called the chromaticity and the ClELAB systems designates this value as "C*".

The C* value is located on a plane beginning at the center of the color space (Figure 1, page 3). Again if we consider a gray sample that is void of all hue, it would appear in the center of the color space with a "c*" value of zero. At this center point, the sample color would have no saturation or chromaticity.

This is not to say that all gray samples have a C* value of zero. There are many shades and hues of gray with varied degrees of saturation, but all of them have C* values close to zero.

Note that 1) the further the C* value of a color appears from the center, the greater its saturation or chromaticity, and 2) C* values can never be negative numbers. So a sample that is void of saturation can never be considered less saturated than a sample appearing at the center of the color space.

DC* Values

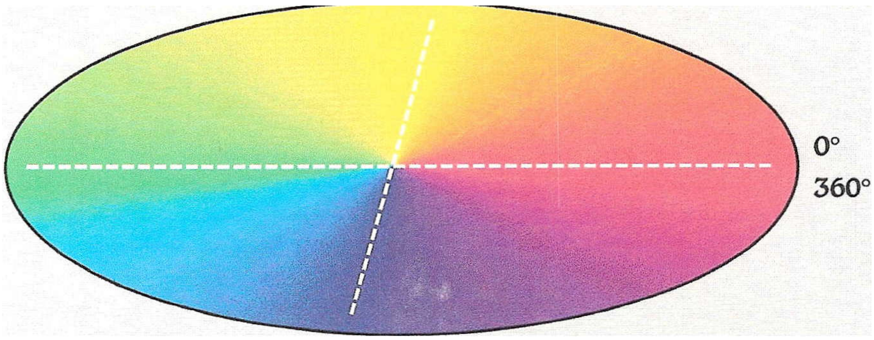
ClELAB generates the Delta C* or "DC*" value by subtracting the standard C* value from the sample C* value. Unlike the C*, the DC* value can be negative (such as -1.54). (See Figure 2, page 4.) Negative DC* values obviously reflect lower saturation and chromaticity than positive DC* values. So if a standard has a C* value of 46.32 and a sample has a C· value of 44.78, the DC* value would be -1.54 (44.78 - 46.32 = -1.54), and the sample would be considered less saturated than the standard.

h Values

The "h" stands for hue which is the actual color recognized by the human eye and identified as orange, yellow, beige, brown, pink or any of the other colors visible to humans. CIELAB computers, however, measure the hue value in terms of geometric degrees as shown in Figure 3 on the following page.

CIELAB System

Figure 3: CIELAB Geometric Degrees



The "h" is represented by degrees of the angle and it can never be a negative number. Because chromaticity (C*) is dependent on the hue (h), the C* value cannot be plotted until the h value has been located on the perimeter of the circle. The C* value must appear on the same plane as the h value. For example, if the h value is 40.00 or 40 degrees, then you could draw a straight line from the center of the color space to the 40 degree point of the circle (Figure 1, page 3). The C* value would appear on the appropriate place on this line. Notice the pie shape created by drawing the line from the center of the color space at 40 degrees.

DH* Values

To calculate the Delta H* or *"DW"* the CIELAB system subtracts the standard h value from the sample h value. For example, if the h value of a standard is 271.27 and the h value of a sample is 269.32 then the DH* value would be -1.95 (269.32 - 271.27 = -1.95). (See Figure 2, page 4.) An h value of approximately 270.00 would be the color blue.

Since the basic appearance of this color is blue, the hue difference between the standard and the sample must be either red or green. If the DH* value is negative-the hue difference would indicate that the sample was "greener" than the standard. If the DH* was a positive number-the sample would appear "redder." (See Figure 1, page 3).

As mentioned previously, a single sample cannot be too blue and too yellow at the same time. So the DH* difference between the blue standard and blue sample would either appear as red or green. The same applies to a *DW* value that is either yellow or blue. A negative DH* value on a red sample indicates that the hue would be "bluer" than the standard. A positive DH* value of a red sample indicates that the hue would appear "yellow" to the standard.

DE* Values

Perhaps the most overused method of determining color approval (or rejection) is the Delta E* or "DE*". The CIELAB system uses the "DE·" calculation as a reference number for setting tolerances. Unfortunately, many quality departments have a tendency to accept this value without considering the other aspects of color such as the lightness, chromaticity and hue.

The DE* calculation is recognized as DE*=[(DL*)2+(Da*)2+(Db*)2] 1/2. By assigning equal value to the three aspects of the sample (lightness/darkness, red shade/green shade, and yellow shade/blue shade) the DE* becomes very arbitrary.

For example, if the DL* value of a sample is -1.00, the Da* value is 0.00, and the Db* value is 0.00, then the DE* value would be 1.00. However, if we evaluate another sample that has a DL * value of 1.00, a Da* value of 0.00, and a Db* value of O.OO-the DE* value would still be 1.00. (Note that the DE' value is always positive because the calculation "squares" the DL', Da' and Db' Values.)

So samples either 1.0 CIELAB unit darker or 1.0 CIELAB unit lighter than the standard can still have the same DE* value. Not many color samples can tolerate this deviation and remain accurate. Consequently, 1) the results of the "DE'" calculation must never be the lone source of setting pass/fail tolerances, and 2) other aspects of color evaluation must be considered.

Important

The industry has supplied a variety of reliable methods of artificial color evaluation. However, it must always be emphasized that the human eye is still the most reliable tool available for analyzing pigmented samples. If, during any color evaluation, the artificially obtained results are unacceptable, the observer must depend on his/her own visual ability to determine the color difference.

A color computer, if not properly used can cause unnecessary rejections or in some cases can cause "off color" materials to be approved. If not used correctly this valuable, time-saving and cost effective tool can prove to be counterproductive. Each and every sample" that is being evaluated by a color computer must also be evaluated by the human observer. Never measure a sample without giving it a visual assessment.