



Using Color Tolerances 101

When visually evaluating color, people often accept or reject color matches based on their individual color perception skills. In manufacturing, this subjectivity can lead to confusion and frustration among customers, suppliers, vendors, production, and management.

How much variation is acceptable?

This is the key question in color quality control and why color measurement instruments are important in color-critical environments. By measuring colors using a spectrophotometer, you can communicate and compare spectral data for exact results, regardless of where you are in the specification, design, development or production process.

But even when using spectral data and tolerances to quantify color, customers and suppliers sometimes still find themselves disagreeing with each other.

Why does this happen?

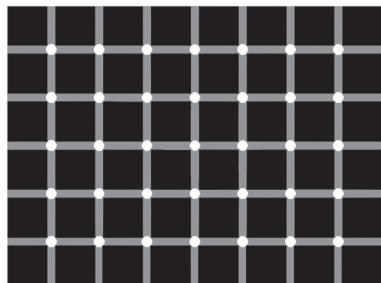
Through the years, different numerical ordering systems have been developed. If a customer and supplier are using different systems, the tolerance – and acceptable color – will be different. In this guide, we look at the most common tolerancing methods to help you be prepared, no matter which method you are expected to use, or others in your ecosystem are using.



▲ A SPECTROPHOTOMETER MEASURES SPECTRAL DATA – THE AMOUNT OF LIGHT ENERGY REFLECTED FROM AN OBJECT AT SEVERAL INTERVALS ALONG THE VISIBLE SPECTRUM. THE SPECTRAL DATA IS SHOWN AS A SPECTRAL CURVE.

Why you can't always count on your eyes

The human eye has limitations when distinguishing color differences. In addition to color memory loss, eye fatigue, color blindness, and viewing conditions, the eye can't equally detect differences in hue (red, green, blue), chroma (saturation), or lightness and darkness. In fact, the average observer will see hue differences first, chroma or saturation differences second, and lightness/darkness differences last.



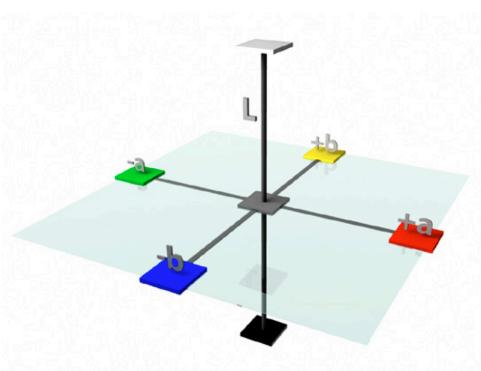
As a result, a tolerance established for an acceptable color match has a three-dimensional boundary with varying limits for lightness/darkness, hue and chroma. Over the years, tolerancing methods have evolved in an attempt to create a method that best correlates to the eye's sensitivity.

◀ “COUNT THE DOTS”: COUNT THE DOTS. ONE, TWO, THREE...
WHAT'S GOING ON HERE? IF YOU FOCUS ON ANY ONE INTERSECTION, IT WILL APPEAR WHITE AND REMAIN WHITE AS LONG AS YOU LOOK AT IT. WHAT ABOUT THE OTHER INTERSECTIONS? THE MORAL IS, YOU JUST CAN'T TRUST WHAT YOU “SEE”.

Methods that improve color interpretation

CIELAB

CIELAB, or $L^*a^*b^*$, was the first internationally accepted color space definition. $L^*a^*b^*$ values are calculated from the tristimulus values (X,Y,Z), which are the backbone of all color mathematical models. The location of a color in the CIELAB color space is defined by a three-dimensional, rectangular coordinate system:



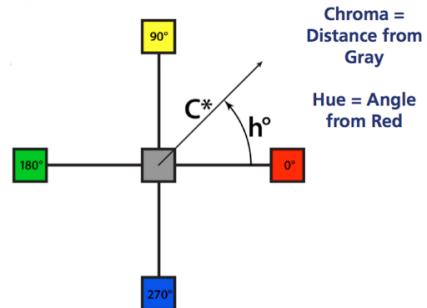
- L^* indicates the color's lightness or darkness
- a^* is the color's position on the red-green axis
- b^* is the color's position on the yellow-blue axis

Once the $L^*a^*b^*$ position of a color is determined, a rectangular tolerance box can be drawn around it to indicate the acceptable color difference. But since visual acceptability is the shape of an ellipse, not a rectangle, there are some places in $L^*a^*b^*$ color space where using a tolerance box may cause problems. Some colors may pass that shouldn't, and some acceptable colors may fail.

$L^*C^*h^{\circ}$

$L^*C^*h^{\circ}$ color difference calculations are derived from $L^*a^*b^*$ values, but mathematics convert the rectangular coordinate system to a cylindrical polar coordinate system.

- L^* is the same as in $L^*a^*b^*$ and represents the lightness plane
- C^* is the calculated vector distance from the center of color space to the measured color. Larger C^* values indicate higher chroma or saturation.
- Δh° is the calculated hue difference between two colors.

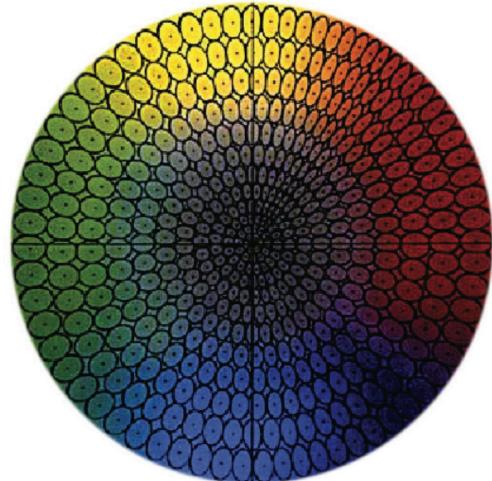


Using the $L^*C^*h^{\circ}$ polar coordinate system to set up tolerancing allows a tolerance box to be rotated in orientation to the hue angle. This more closely matches human perception of color, which reduces the chance of disagreement between human observer and instrument readings or values. The $L^*C^*h^{\circ}$ system more closely relates to human perception, but still is not as accurate as it could be.

CMC, CIE94, and CIE2000

The most current and accepted tolerancing methods are elliptical – DECMC, CIE94, and CIE2000. These are not new color spaces, but rather are color difference calculations that are based on the color's location in color space. This provides better agreement between visual assessment and instrumentally measured color difference.

Although we have not yet devised the perfect color tolerancing system, these elliptical tolerance methods best represent how we see color differences and are recognized standards in many industries.



Visual Assessment vs. Instrument Measurements

Though no color tolerancing system is perfect, the CMC and CIE94 equations best represent color differences as our eyes see them.

Tolerance Method	% Agreement with Visual
CIELAB	75%
CIELCH	85%
CIE94 or CMC	95%

What can you do to avoid confusion and subjectivity in tolerancing?

1. Select a single method of calculation and use it consistently.
2. The amount of acceptable tolerance varies by industry and application. For example, the tolerance for a plastic bubble container will be higher than the plastic dashboard for a \$35,000 car.
3. When you're discussing color difference, be sure you're talking about the same tolerancing system.
4. When you're setting the acceptable tolerance within your color measurement instruments and software, you must also select the tolerancing system to calculate accurate results.
5. Never attempt to convert between color differences calculated by different equations through the use of average factors.
6. Use calculated color differences only as a first approximation in setting tolerances, until they can be confirmed by visual judgments.

To learn more about color models and tolerancing, consider our traveling **Fundamentals of Color and Appearance seminar**.

Check to see when we'll be near you.