Keeping up appearances

Color, gloss measurements add science to the art of selecting coatings that will hold their appeal

Gloss measurement being performed on a weathered architectural detail too large for in-laboratory measurement. Photo courtesy of South Florida Test Service

Passing the test
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We've all driven by the travel agency with the poster in the window … the sculpted, golden-tanned newlyweds frolicking in the azure blue sea against a backdrop of white sand beaches and waving palm trees, with pillowy-white clouds floating in an aquamarine sky. And after several months of commuting past that idyllic poster, the now magenta-sunburned newlyweds frolicking in split pea soup against a washed-out sky has lost its visual appeal.

The effects of sun, weather, and time can also make architectural coatings change appearance and perhaps lose their appeal. So how is the architect to understand coatings color and appearance ratings, testing, and specifications?

Color communication and appearance measurement is a complex science, but a fundamental understanding of the basics is usually all that is required to grasp coating ratings and specifications—not only for initial selection, but also to gauge the long-term appearance probability and the likelihood of maintaining good appearance with cleaning, maintenance touch-ups, etc.

Coatings primarily owe their overall color to a combination of colored pigments, although neutral pigments, fillers, and extenders such as titanium dioxide and calcium carbonate can also play a role. So, too, can the binder, which cures to form the dry paint film—especially if it is prone to yellowing over time, as may be the case in epoxies and aromatic urethanes.

Pigments and color loss

Pigments that are inorganic (metal or mineral) in nature, such as red iron oxides (a.k.a. "rust"), are typically very light- and weather-stable throughout their lifetime. A drive in the country will quickly show that older—now banned—red-lead barn paints didn't fade; the coating may disappear from the structure, but the color that remains is still strong.

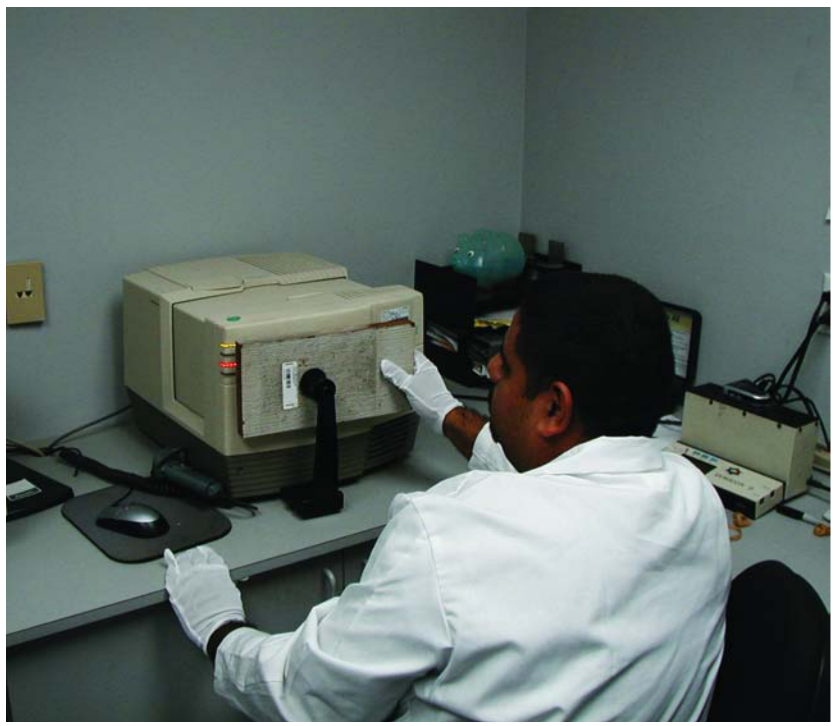
Most of these inorganic pigments, though fade-resistant, don't provide the more intense saturation and vivid colors now often preferred in coatings, e.g., "fire-engine red" versus the muddier "barn red." These more intense colors are usually obtained with synthetic organic pigments. While there are some very light-stable organics available, as a class they generally are not as lightfast and tend to fade with light and weather exposure. As coatings based on these pigments age, they tend to lighten, or fade. This is particularly true in higher-sunlight areas such as the U.S. South and Southwest.

South-facing facades (in the northern hemisphere) also see higher levels of solar radiation and fade faster, as do horizontal or angled surfaces. This can be a problem when a structure is viewed from different angles, because the eye is pretty good at picking out relative differences of adjacent colors. Ideally, if a coating is going to fade, it should fade relatively uniformly, regardless of orientation.

For the coatings formulator, another issue is the "tint strength" of a pigment, or how much pigment is required to reach a certain color intensity. Coatings with higher pigment concentrations can be more fade resistant than coatings with lower concentrations of pigments and similar inherent lightfastness simply because they contain more pigment.

Fade, or lightening/loss of color with exposure, however, is only one aspect of color change. There are thousands of colors available, but a limited number of pigment chemistries. Most colors are made from a mix of different pigments. For example, there is no cedar-tan colored pigment, but coatings can typically be formulated from five to seven pigments to achieve the cedar color. Usually coating manufacturers will offer several possible formulations of different pigments to achieve the same final color. "Green laws" and environmental restrictions on heavy-metal pigments such as lead and hexavalent chromium have forced reformulations of many traditional coatings colors, sometimes resulting in issues of the durability of appearance .

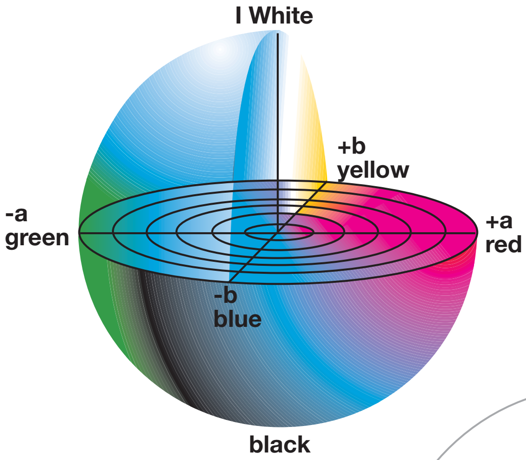
If one or more pigments fade at different rates, the result can be an actual hue, or color, shift. In one striking example, a stable "salsa red"-colored coating was reformulated with new, environmentally friendly pigments—inorganic carbon black and titanium dioxide—to provide a lightness level, and a mix of organic red, blue, and yellow pigments to provide the burgundy tint. On sunlight exposure, the red pigment quickly faded, resulting in a color shift from red through bronze to green as the red disappeared. The new formulation met the stringent initial color-match spec, but was not adequately tested for environmental durability of color retention. While special-effect, color-shifting pigments are hot in automotive applications, the result was less satisfactory on a building.

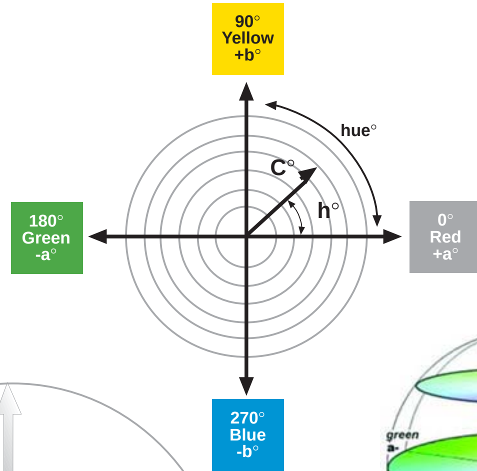


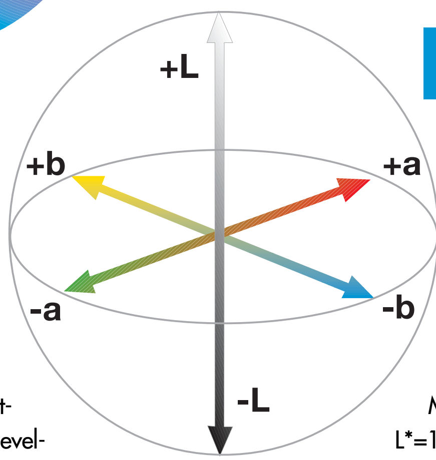
An evaluation technician measures color change on painted wood test panels in a special environmentally controlled laboratory. Photo courtesy of South Florida Test Service.

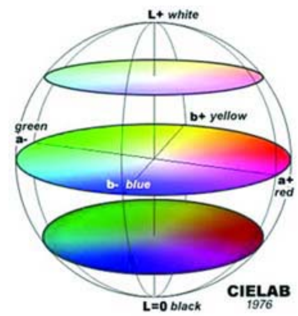
Standardizing colors

So how can color description be standardized? First, it is important to understand that color is not a physical property of materials but rather a perception—a human interpretation of color based on three key components: the light source, the object itself, which modifies the light, and the observer, whose eye and mind perceive color and appearance.









In CIE L*a*b* measurement, any color can be defined by it's 3-dimensional rectangular coordinate in color space.

Human beings can differentiate between about 10 million different colors, but our ability to interpret and describe them varies widely. The same individual can perceive color differently based on factors such as illumination, viewing angle, and even mood.

One of the first wide-scale systematic attempts to categorize color was developed by American artist A. Munsell in 1898. He established a "globe," with the axis being a scale of neutral gray values, with pure white as the North Pole and black as the South Pole. Around the equator ran a band of colors. Extending outward from the axis like spokes at each gray value was a series of graded colors progressing from neutral gray to full color saturation. With these three defining qualities of hue (basic color), value (lightness) and chroma (depth or saturation), any color could be mathematically described as a location in the three-dimensional globe.

This system was not without its flaws, however. For example, darker hues (colors) such as reds, blues, and purples tend to have higher chroma values at full saturation (depth of color further from the axis) while yellow and greens are weaker hues that average full saturation relatively close to the neutral axis. This makes numerical differences dependent on hue and difficult to compare, but these values are still sometimes quoted in coatings information (ASTM D-1535, *Standard Practice for Specifying Color by the Munsell System).*

In 1976, the CIE (Commission Internationale de l'Eclairage) established standard values that are used worldwide to measure color. The values used by CIE are called L* (L-star), a*, and b*, and the color measurement is called CIELAB (the full name is CIE 1976 L*a*b*). In CIELAB, a color is represented by three numbers that specify its coordinates in a three-dimensional volume. As with Munsell, L* represents the difference between light (where L*=100) at the top and dark (L*=0) at the bottom of a vertical axis. Measurements are standardized in ASTM E-308, *Standard Practice for Computing the Color of Objects by Using the CIE System.*

The human eye perceives color as the following pairs of opposites: Light-Dark, Red-Green, and Yellow-Blue (called the Opponent Colors Theory). This theory says that a color cannot possess both red *and* green or yellow *and* blue components at the same time. Thus, a* represents the difference between green (-a*) and red (+a*), and b* represents the difference between yellow (+b*) and blue (-b*).

Using this system, any color can be described by its three-dimension L*a*b* coordinates. A CIELAB of 50,75,5 would be red, while 50,-75,5 would be green, and a yellow could be 70,0,80. Two samples that are the same color and change only in lightness would be, for example, 50,50,50 and 75,50,50.

Because colors are specified in terms of numbers, it is relatively simple to go one step further and describe a difference in two colors. A difference, or delta (D or Δ), of DL*=20 means that the color has faded, such as the washing out of the blue sky in the travel poster, while a Db* of +20 means that the color has shifted more yellow, such as the yellowing of a white paint. A combination of a Da*=20 and Db*=-15 means that the basic hue has shifted, such as the tanned honeymooners in the poster looking magenta.

In general, a hue shift is much more noticeable than a pure chroma (saturation) or lightness change, but this can be highly subjective. For example, a slight shift in skin tone towards the green is much more noticeable and objectionable that a similar value toward the red. An additional combined value of the deltas in L*,a*b* values has been created to provide a single value to express a total color change value: *delta E*, where $DE=(DL^{*2} + Da^{*2} + Db^{*2})$. Delta E represents the magnitude of difference in color but does not indicate the direction of color difference, such as fading, yellowing, or hue shift.

Measuring color shift

The American Architectural Manufacturers Association specifications for architectural coating color retention after 5 years (AAMA 2604) or 10 years (AAMA 2605) of outdoor South Florida weathering require a delta E of 5 or less. So, is this a huge change or barely noticeable? From a practical standpoint, most people find it difficult to discern a delta E of 3 or less, and a delta E of 5 is quite subtle (unless it results in a noticeable hue shift such as green-tone skin).

Before measuring instruments became common, visual color measurements were the norm, and they are still widely employed. Because colors can appear different under different lighting conditions—a process called metamerism—visual color assessment is done under defined viewing conditions. In general, the test panel is

A weathering laboratory technician performs a field measurement on an architectural detail for color change. Photo courtesy of South Florida Test Service.

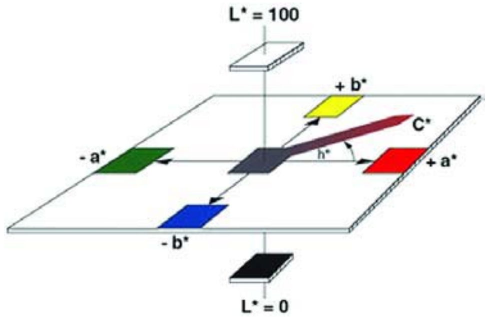
illuminated from above or behind at a 45-degree angle and the observer views the panel head-on, or perpendicular to the test plane.

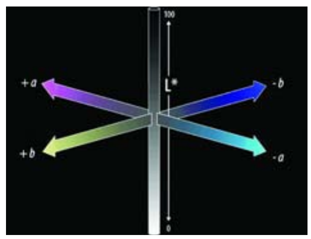
While viewing can be as simple as moving to a sunlit window, the standard technique calls for a viewing box, booth, or room, dimly lit and painted neutral gray. The illumination is usually specified as D65, or indirect northern light in terms of color. Other illuminants such as direct daylight, incandescent, and fluorescent can also be specified. The guiding standard is ASTM D-1729, *Standard Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials.*

Visual assessment can be used both for color matching two specimens or for determining the amount of color fade or change against a reference panel, such as comparing weathered and unweathered panels. The most common rating scale is based on the "gray scale" (ASTM D-2616, *Standard Method for Evaluation of Visual Color Difference With a Gray Scale*).

Originally developed for measuring textile fade, the AATCC Gray Scale is still widely referenced for coatings. A series of ten pairs of gray tones, each pair differing by a greater amount, is compared to the weathered and unweathered specimens and the relative amount of fade is determined by matching the panels to the pairs on the scale. The scale is most effective when used for faded samples where there is no hue shift because the color component of non-gray test specimens can make visual assessment tricky, especially for untrained observers. A CIE delta E of 0 (no change) corresponds to a Gray Scale of 5, and a delta E of 3.6 corresponds to a Gray Scale rating of 1. The scale ranges from 1 to 5 in 0.5 unit increments.

In general, most coatings companies report color change, such as that measured after weathering, in terms of delta L*,a*,b* or delta E values. There are, however, several alternative scales. Of these, the CIE L*C*h Color Scale is most likely to be encountered. The CIELCh scale values are calculated from the CIELAB scale values and the L* (lightness) value is the same in each scale. The C* value (chroma) and the h value (hue angle) are calculated from the a* and b* of the CIELAB scale. The L*C*h color space uses the same diagram as the L*a*b* color space, but employs cylindrical rather than rectangular coordinates. C* is the chroma and has a value of 0 at the central neutral axis and increases according to the distance from the center. Hue angle *h* is defined as starting at the +a* axis and is expressed in degrees as the chroma axis rotates counterclockwise.





In CIE L*C*h measurement, a color is alternatively defined by its angular polar coordinates.

Most paint companies today offer in-store color matching. With these systems, one simply places a paint or fabric sample over an optical measuring device and the formula for matching paint is fed by the computer to the tint-mixing station. These systems measure the color according to the same CIE values described, and also contain a database of the particular tint colors available. The tint strength and hue of each colorant is carefully computed so that the combined pigments result in the matching shade. Problems of mismatch can arise if a precise match with a given set of tints is not possible, or if the new tint system metamerizes under a different lighting condition, such as interior lighting.

When using either CIE L*a*b* or L*C*h coatings for production, batch color quality control manufacturers face a problem—separate color tolerances for different colors or color families are required and may not always agree with visual color difference. A modified version, called CMC, is used, which allows for a single tolerance value for all shades and for better correlation with visual assessment. These values, however, are rarely reported and are of little use to the architect. Other color measurement systems such as XYZ Tristimulus values, Yxy Color Space, CIELUV, and Hunter Lab are also rarely encountered in architectural coatings.

Gauging gloss and determining DOI

Gloss is another appearance attribute that is very important for many coatings. Gloss measurements quantify the amount of light reflected from the object's surface at the specular angle; this is the angle equal to but opposite the angle of incidence.

Gloss measurements are almost always performed instrumentally, and a green filter is usually placed in front of the detector to better simulate the response of the human eye. High-gloss coatings are generally measured at a 60-degree angle (incidence and specular), although other angles, such as 20 or 85 degrees, may be used; the angle must always be specified with the reported value. High-gloss coatings may give initial gloss levels of 85% or more (100% would be a mirror surface).

As a coating's surface starts to degrade from weather and environmental exposure, the top erodes unevenly and scatters light in all directions. As the surface further erodes, gloss levels generally decline until they reach a low, relatively steady-state level. The amount of total gloss loss after a period of weathering is often a good indicator of coating performance as well as a guide to eventual appearance. It should be noted, however, that a slight gloss loss from an initial very-high gloss coating will be much more noticeable than a similar loss from a coating with low initial gloss. Gloss measurements are performed according to ASTM D-523, *Standard Test Method for Specular Gloss.*

Gloss is an appearance property that is greatly affected by the coating substrate and both the thickness and evenness of the coating itself. Coating application resulting in lap lines is particularly noticeable with higher-gloss coatings, and maintenance touch-ups are often visible due to gloss differences. The ability of a coating to mask these application defects is determined by ASTM D-3928 *Standard Test Method for Evaluation of Gloss and Sheen Uniformity;* ratings range from 0=Very Poor, through 6=Good, to 10=Excellent.

Another measurement of surface appearance is Distinctness of Image (DOI). This is a quantification of the spread of light reflected at the specular angle, and it gives an indication of how sharp the image reflected by a coating is likely to be. For example, a ruler placed vertically against a highly polished (mirror) surface would allow the numbers to be clearly read in the reflected image. Conversely, a similar flat, smooth, shiny surface might have the same gloss level but the image would not be as distinct. DOI meters are similar to glossmeters but give a ratio of the measurements of the specular-angle reflected light and the light slightly off the specular angle to calculate the DOI.

DOI is widely reported for automotive basecoat-clearcoat finishes and is finding its way into architectural specifications as clearcoats become more widely used for appearance retention.

The measurement of color and key appearance properties such as gloss for both new and aged architectural coatings is important to understand when specifying or comparing architectural coatings. How much a coating may fade or shift in hue under sunlight exposure may determine whether a particular color should be used. Gloss and sheen uniformity may indicate whether a coating will be difficult to apply or maintain.

Evaluations of color and gloss retention, used in combination with other ratings such as washability, scrubbability, burnish resistance, and mildew resistance provide the architect and specifier important information in evaluating long-term performance as well as the overall cost effectiveness of a coating system.

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