Technical Guide 103

A Brief Guide to Color Measurements In Weathering

Introduction

Color change is one of the parameters most often measured in weathering tests of materials and products. This is usually manifested as (1) a color fade, (2) the development of color, such as yellowing, and (3) hue shift, which can be caused by either a change to one or more colorants, or the development of color through polymer degradation, or another mechanism such as "gas fade", which results in coloration/discoloration. However, many, especially those new to weathering, are unfamiliar with basic color measurement concepts, the color measurement scales available, and their terminology. This will serve as a very brief introduction to color measurement.

Color change can be estimated visually, or more precisely by instrumental methods. Often, we are interested in the specific type and amount of color change during a weathering test or other exposure. To determine the degree of change we need to compare "before" and "after" exposure data. Frequently, period measurements at repeating exposure intervals will be performed and plotted to construct a degradation rate graph. For visual evaluations an unexposed "retain" sample will be needed for side-by-side comparison to the exposed specimens. With instrumental color measurements, the initial (t_0) reading is made on each specimen prior to exposure, then during the exposure and/or at the end of the test. Due to normal variability it is customary to measure at 3 (or more) locations on the specimen and average the values.

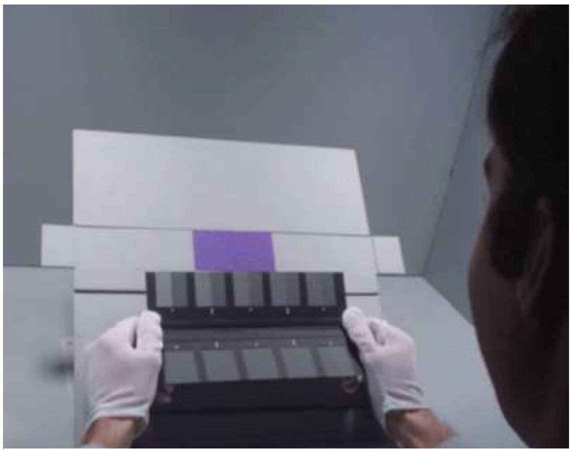

Figure 1. Visual color change assessment using an AATCC Gray Scale.

Visual Evaluations

Evaluating color visually is often sufficient for non-critical applications or where precise pass/fail ratings are not needed. Also, humans process and perceive color differently than instruments, and are pretty good at detecting side-by-side color differences. However, everyone sees color differently (and some people are colorblind), so ratings are often imperfect.

One common rating system, often used in the textile industry, is to use a standardized gray scale for color change. These are documented in *ISO 105-A02 Textiles – Tests for colour fastness – Part A02 Grey scale for assessing change in colour* and *AATCC* Evaluation Procedure 1-2007 Gray Scale for Color Change (Figure 2)*; these two are technically equivalent. This method primarily is used where color fading (or darkening) is the predominant change and compares the before and after specimen against a series of contrasting gray shades to numerically rate the degree

* AATCC is the *American Association of Textile Chemists and Colorists;* ISO is the *International Standards Organization*

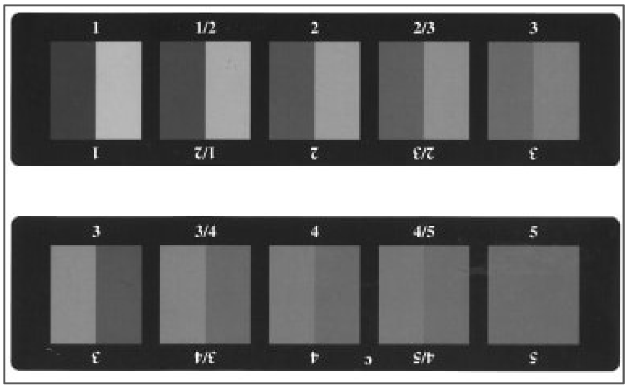

Figure 2. ISO/ASTM Gray scale for visual assessment of color change. Units range from 1 to 5 in 0.5 unit steps.

of change. Evaluations are performed under standardized lighting conditions in a color matching booth. The ISO scale is technically equivalent. Two other scales are sometimes used for very light colors, the AATCC and ISO Gray Scales for Staining (Figure 3). These are for evaluating color transference/staining although not typically used in weathering or color fade test evaluation. One disadvantage of all visual measurements, however, is that they really provide no information on the direction of any color change other than a change in the light/dark parameter.

Figure 3. The AATCC and ISO Gray Scale for Staining. Ratings run from 1 to 5 in 0.5 unit steps.

Instrumental Color Measurements

Instrumental measurements are made with a laboratory bench mounted or handheld portable colorimeter. There are several different scales that are used for quantifying color, and some industries have a preference. However, the most widely used is the CIE System, developed by the *International Commission on Illumination* (CIE, abbreviated from the French *Commission Internationale de l'Eclairage*). The CIE color system was developed on the premise that color is the combination and interaction of light energy, an object and an observer. In 1931 the CIE developed a color definition that could be used to represent a color viewed under a standard light source by a standard observer. In 1976, the CIE Uniform Color Space was developed to refine the original scale, and today the most widely used is the CIELab scale. It is based on the response of the three color (red, green and blue) receptors in the human eye and the perception of light/dark. A color cannot be both light and dark, or red and green, or yellow and blue – at the same time; these colors are opposites on the color wheel.

*CIE L*a*b**

The CIE L*a*b* (L star, A star, B star) scale defines any color by its coordinates on a three-dimensional color space scale (Figure 4). There are three axes:

L* is a measure of the lightness of the specimen and ranges from 0 (black) to 100 (white).

a* is the red/green axis; +a is the red direction, and -a is the green direction with 0 being at the intersection with the L* axis.

b* is the yellow/blue axis; +b is the the yellow/blue axis; +b is the yellow direction, and -b is the blue direction. A specimen that yellows will show an increase in the b+ value direction.

When specifying a color tolerance for color matching or color change, such as from weathering exposure, the target with ± tolerances is usually defined as a three dimensional (hue, chroma and lightness) elipsoid, since the different axes may not all have the same tolerance values. Hue is the color (position on the a/b axes), chroma is the saturation or depth of that color (distance from the center axis), and lightness is the L axis,

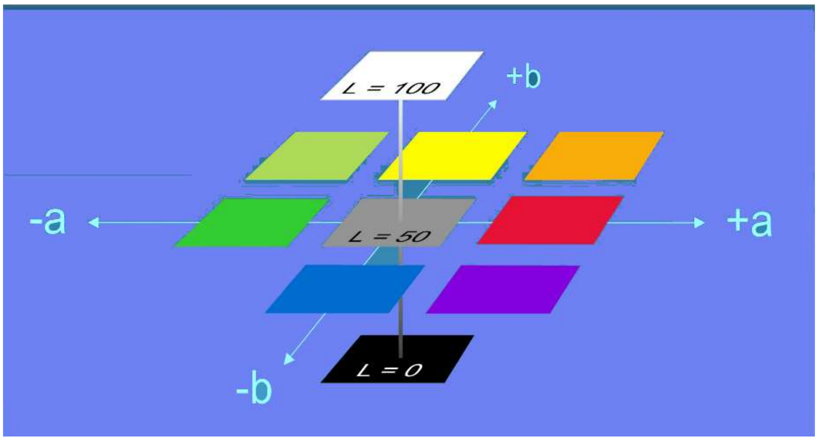

Figure 4. CIE L*a*b* value defines a color by its 3-dimensional coordinates on this scale.

The L*a*b* color space describes not only color fading or darkening, but also any hue shift (change in color direction). The change, or delta (Δ), in any of these values can be informative. An increase in Δb+, for example, indicates an increase in yellowing, common for plastics and coating resins in weathering degradtion.

CIELab Delta E

Often, it is desirable to use a single number to define a total color change value. This is especially true for specifications, such as the acceptance criteria for products, as a single numerical value is easier to specify for pass/fail parameters. The total color change, or Delta E (ΔE, *de*) is described by the following formula:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2} \quad \text{Equation 1.}$$

The formula is simple as it is merely the square root of the sum of all of the changes squared: $\Delta L^2 + \Delta a^2 + \Delta b^2$. Delta E values can range from 0-100. It is really a distance between two color space points on the CIE L*a*b* three dimensional color space (Figure 4).

Delta E, while useful, does have limitations. It does not describe the type of appearance change. Did blue colored ABS plastic used for automotive trim fade as well as turn yellow resulting in a color (hue) shift to green? Delta E by itself won't provide any of that detail. Also Delta E differences can be perceived as more or less severe for different color changes, and we perceive changes in light/dark differently than for color direction. To put this into perspective, a ΔE=1 is *generally* considered the minimum that can be visually detected. A ΔE=3 is *generally* considered the minimum color difference that *most* people can detect and is a very common specification value for pass/fail color change after weathering. However, a high chroma color can have a much higher ΔE with little to no visual difference, whereas lighter colors/pastels can note visual differences at 0.50 ΔE, or even less. So, while an imperfect scale, it is most used.

For those new to weathering tests and color measurement there is often no perception of what measurement scales like AATCC/ISO Grey Scale, L*a*b* or Delta E really mean. It often comes down to "I'll know it looks bad when I see it". In that case a "pull & return" approach to weathering testing provides a better option. Here, a replicate specimen is pulled from exposure at various (usually equal) exposure intervals and archived. This provides a "story board" of actual exposed samples at various stages of weathering exposure. This is often useful for sales presentations (this is what to expect) or for setting color change specifications. It does require starting the test with a larger specimen count. Usually an area of approximately 1.

Other Color Scales

It will be briefly noted that other scales, such as Hunter L*a*b*, CIE XYZ and CIE L*C*h* also exist, however CIE L*a*b* is most commonly used in weathering. These systems include HunterLab, CMC, Munsell, etc., but are beyond the scope of this document. Be aware that numerical conversions from one system to another are not always accurate.

Yellowness Index (YI)

Yellowness Index is a number calculated from colorimetric data that describes the change in color of a test specimen from clear or white to yellow per *ASTM E313 Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates* or *ASTM D1925 Standard Test Method for Yellowness Index of Plastics* (withdrawn but still referenced). This measurement is most commonly used to rate color changes in a material caused by real or simulated outdoor exposure.

Instrumental Color Measurement Parameters

Both the eye and an instrumental colorimeter need three things to “see” the color of an object: a light source, the object itself, and an observer. These must be specified in instrumental color measurements.

Illuminant

Colors may appear different under different illuminants, such as outdoor daylight v. “daylight” fluorescent, LED lamps or other sources, including light reflected from colored objects such as walls. CIE uses several standard illuminant types, however Standard Illuminant D65 is most commonly used in weathering, with others being used for non-daylight sources such as tungsten, fluorescent lamps, etc.

ISO 11664-2, Colorimetry -- Part 2: CIE standard illuminants, defines the illuminants. Illuminant D65 is intended to represent average daylight and has a correlated colour temperature of approximately 6,500 K. CIE standard illuminant D65 should be used in all colorimetric calculations requiring representative daylight, unless there are specific reasons for using a different illuminant. Variations in the relative spectral power distribution of daylight are known to occur, particularly in the ultraviolet spectral region, as a function of season, time of day, and geographic location. However, CIE standard illuminant D65 should be used pending the availability of additional information on these variations.

Standard Observer

ISO 11664-1, *Colorimetry -- Part 1: CIE standard colorimetric observers*, defines the “observer” and is based on the average human response to the wavelengths of light. The options are 2° (which is the most common) and 10° observer angles (based from the perpendicular).

Object

This isn’t something you specify, but measurements can be made in transmission mode for transparent objects, or reflectance mode for transparent and opaque objects. In reflectance mode, the gloss of an object can affect the measurement, and there is one parameter that *does* need to be specified. Gloss is simply a measure of specular reflection.

In a perfect mirror, the incident light beam is reflected at the same angle and intensity. If the surface is has very low gloss, most of light is scattered in all directions. In between these extremes, a glossy surface will reflect most of the light forward in both the specular and near-specular diffuse components, as shown in Figure 5:

- **High gloss surfaces** cause a strong specular reflection of light and weak diffuse reflection of light, resulting in a more saturated, vivid color
- **Semi-gloss surfaces** cause the specular reflection of light to mix with the diffuse reflection of light, resulting in a less saturated, lighter color
- **Matte surfaces** cause a strong diffuse reflection of light and weak specular reflection of light, resulting in a less saturated, duller color.

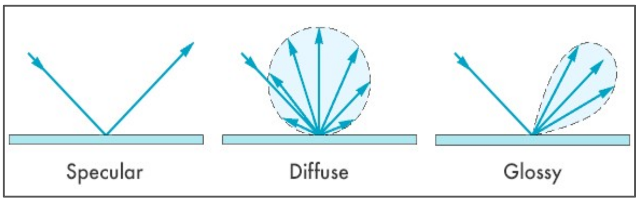

Figure 5. Gloss is comprised of the specular reflected beam. Scattered diffuse light results in a loss of gloss.

In color measurements the specular component can be *included* (SCI) or *excluded (SCE)* and needs to be specified. SCI is usually used to measure the "true" color of the object while SCE is more typically used to measure the appearance of an object. SCE is more sensitive to the surface characteristics of the object and usually the values fall in a region that is lighter and less saturated (chroma) of the color space than SCI measurements. SCI is mostly used in weathering test measurements as it is closer to measuring the true color characteristics. Since the human eye evaluates both color and gloss for an appearance property, SCE is more useful for color matching applications as this is how the eye detects it and the brain perceives it.

Other factors

Many other factors, such as fluorescence (e.g., from optical brighteners), the nap of fabrics or other surface texture, measuring in different locations or with different specimen orientation, the background or backing material etc., can influnce color measurements but are beyond the scope of this brief introduction. In general, a minimum of 3 replicate measurements are made on a sample, usually in different areas, and averaged.

Standard Reference Materials

Finally, there are a number of standard reference materials (SRMs) available such as Polystyrene (PS) plaques, ASTM and ISO Blue Wools, ORWET coating, etc., that are available to run as control samples in weathering tests. These help assure that artificial weathering instruments are delivering the proper test conditions.

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