

# COLOR FOR COMPOSITES - AN OVERVIEW

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Since the advent of modern computer color systems, colorant users have been working with sophisticated equipment to evaluate colored materials with the hope of solving critical color control problems. When mismanaged these instruments may yield results that are erroneous, or at least not what the user expected or needed. As with other computer-based systems, the value of the data received from color measuring devices is only as good as the time, thought, and materials used in sample preparation and measurement. Due to the lack of proper training, the colorant user may be unaware that the information, diligently pursued, may not be meaningful. Sometimes colorant users prefer not to do the color work in-house and request the task be completed by their pigment supplier. The scenario usually goes like this: the resin formulator receives, from his customer, a request for a colored part; the formulator sends the match to a pigment dispersion house and requests a colormatch; the dispersion technician derives a colormatch in the customer's system, makes a sample, and sends the sample to the formulator who tools and molds the part.

Frequently, the color of the molded part is not the color the customer wanted. Sound familiar? The dispersion supplier reports "the color's right on" but the formulator has a part which is aquamarine instead of sky blue.

Once this series of events occurs, the shaken formulator questions the colorant supplier's competence and inquires why the color was off - "You had my system." Before we can resolve this or similar problems, we must determine what color is, why and how it exists, and examine the physical variables which contribute to the color of objects.

It is not the purpose of this paper to make the reader a colorist, but rather to provide a brief overview of the nature of color. Hopefully then, when things go wrong there will be a forum for discussion leading to problem solving.

Imagine for a moment, that you are standing on a New England hill, in early October. The foliage is changing, red leaves are vivid, the yellow and orange leaves are just beginning to display their beauty. The sky is blue, and in the valley foreground is a beautiful little white church with a tall spire; the sun seems to sparkle from it. Or, imagine you are walking through a meadow of brightly colored wild flowers early on a summer morning. The dew is glistening from the sunlight and at the far end of the meadow a deer is feeding near the thicket.

It is not difficult to imagine these colorful scenes. But how would we feel about these images if we couldn't have color, if everything in these scenes were just black and white or shades of gray? There would be something missing. We could

identify the objects in the scenes, but our level of satisfaction and personal enjoyment would not be as great without the reality of color.

### What Is Color?

Color exists primarily because three components act simultaneously to produce a response, COLOR. In our earlier scenes, all three components were described. We mentioned light reflecting from a steeple or sunlight enhancing the dew. In each scene there was an object to be viewed, a beautiful New England leaf setting, or a pretty meadow on a summer morning. And lastly we had an observer, somebody or something to view the response. Oftentimes, the observer is you. The contribution to the scene by the observer is to interpret the visual stimulus.

As a result, color exists because light strikes an object and the response is viewed by an observer. Let's look at each of these three components more carefully as we develop a process leading to color.

### The Light

The color of an object originates with the light source illuminating it. What is the nature of light which stimulates the eye and allows the observer to appreciate color?

Visible light is a narrow region of the electromagnetic spectrum, described in wavelengths from 380 nanometers to 740 nanometers. A nanometer is equal to 10 angstroms or 1/1,000,000,000 of a meter.

"White light" can be broken into spectral energy hues. They are red, orange, yellow, green, blue, indigo, and violet. The periodic wave interval correlates to the color; for example, red light is visible energy with relatively "longer" wavelengths, while violet light results from visible energy with "shorter" wavelengths. The radiometric curve, measured from a light source, is a description of the relative quantity of energy across the different hue bands of the visible spectrum. Graphing the energy versus wavelength gives a spectral energy distribution for the source. Light sources include natural sources, daylight or sunlight, and artificial sources such as incandescent or fluorescent lamps.

Often confusion results as to the color of natural or artificial sources. Two lamps can be described as "white light," but may be a matter of energy intensity rather than color, as their energy distributions could vary spectrally. An interior designer may select an incandescent source, producing a yellow cast, for soft lighting effects in a formal setting. A cool white fluorescent lamp, on the other hand, may be used to brighten a kitchen. A cool white fluorescent light has considerably more blue energy and less yellow-red energy than an incandescent lamp.

Some sources have become standardized for the purpose of describing color. These sources are called illuminants. Illuminants may not represent physical

sources but theoretical values for the color measurement calculation. When physical forms of illuminants exist, they are called standard sources. Examples of illuminants are: CIE Illuminant A (tungsten lamp operating at a correlated color temperature of 2854° K); CIE Illuminant C (filtered CIE Illuminant A operating at 6700° K); and, more recently, CIE Illuminant D, representing phases of actual daylight. The CIE: in English, is the International Commission of Illumination, an international organization concerned with the measurement of color.

### The Object

Light plays a major role in what we describe as color, but light is only one component. Light must be modified by an object. Color reaching the eye is radiant energy which has been changed or modified by the selective absorption qualities of the object.

Transmission of light means that light goes through an object, while reflection implies the return of energy from a surface. Some transparent materials appear colored. In these instances, the light enters the transparent medium and is selectively absorbed, allowing only certain wavelengths of light to exit the medium, thus providing color. The degree to which the absorption occurs dictates the darkness of color. If all of the light had been absorbed, the object would be an opaque black. Absorption is the process of incident energy being "lost" as a result of the object modifying the energy from one form to another; such as, from light to heat.

When incident light strikes an object, a small portion of the light is reflected at the surface. This reflected light or glare is described as the specular component. The majority of the light energy penetrates the object and strikes, in a ricochet fashion, the pigment particle and system interfaces of different refractive indices, diffusing the light. This process is called scattering. As the rays of light pass through the pigment medium, selective absorption occurs; the object takes on its distinctive color. A composite part appears blue because the colorant absorbs the yellow light and allows only the blue energy to be reflected to the observer.

Spectrophotometers, described later, are used to measure the reflected or transmitted energy response of an object.

### The Observer

When light is modified by an object, if an observer or detection device is not present for the response, color as we understand it cannot exist.

Studies continue in color related fields as to the effects of light on the eye. Simply stated, light passes through the cornea lens and is focused on the cones and rods in the retina. The cones are sensitive response elements which react to light energy in terms of the quantity of visible blue, green, or red energy. The rods are intensive receptors which provide clarity of image and permit the eye to discern images at different levels of illumination. In low light situations, there is not

enough energy for the cones to function, and our vision is primarily black and white images.

On a sunny day an observer can see sailboats, brightly colored on a blue lake (cones), while under moonlight conditions the sailboats only appear as gray forms floating on the water (rods). Once the light energy strikes the eye and the cones and rods are activated, the optical image is converted into a nerve pattern and transmitted to the brain by the optic nerve for interpretation.

The CIE adopted specific values for the visual response of an average population of standard observers. These values,  $x$ ,  $y$ ,  $z$ , are called the CIE Standard Observers, and they correspond to the visual blue, green, and red response of an average population. The Standard Observers play a prominent role in the quantitative description of color which will be discussed later.

### Appearance and Metamerism

Before we proceed further let us mention two fundamental terms of color science, appearance and metamerism.

The appearance of an object and the color of an object may not always be the same. Two objects may contain the same colorant formulations, are illuminated and viewed under similar conditions (we say the color is the same), but due to surface or surround effects the two objects may have different appearances. Appearance is more than color and includes the elements which help us recognize things, such as viewing geometry, lighting conditions, and surface aspects, such as: size, shape, surface texture, transparency, translucency, opaqueness, etc. In this paper no additional attention will be given to specific conditions which contribute to the appearance variations, of objects.

Metamerism results when a pair of specimens, which do not have the same spectral curves, match under at least one set of viewing conditions, but cease to match when the viewing conditions change. Whenever the components which contribute to the color of the metamers change the spectral response of the observer, the light source, or the viewing geometry, the metameric pair no longer matches.

### Laboratory Tools

To this point, our discussion has been on the visual aspects which relate to the color of objects. Now, let's look at laboratory instrumentation which measure the visual response and produce quantitative information about a specimen's color.

There are two common instruments in the color laboratory: the tristimulus colorimeter and the recording spectrophotometer. A colorimeter is a tool which uses colored filters to determine color differences between pairs of non-metameric samples. Colorimeters measure only select color bands. As a result,

they can provide no information concerning metamerism and are of little value for color matching. The colorimeter can, however, produce useful information about specimens made up of similar components, but its output values are not absolute and should only be used for comparative purposes.

The spectrophotometer, on the other hand, is the primary tool for measuring reflectance and/or transmittance. The instrument output is response (reflectance/transmittance) versus wavelength. Spectrophotometers integrate the energy of a source and separate the energy, by a monochromator, into the individual hue elements of the visible spectrum. A narrow slit is placed between the monochromator and the sample. The narrow band energy passes through the slit and strikes the sample; the response is detected and compared to a standard or previously calibrated data. The result of the comparison is a spectral curve which is a "finger print" for the object, and provides information for color measurement calculations.

### Describing Color-Color Order System

It is apparent by now that color exists because light, objects, and observers work interactively. But, how do we convert this information into an orderly pattern for the purpose of colormatching, system process, or quality control?

Color order systems use words, symbols, and numbers which characterize the color of an object and organize it in a systematic manner. There are many types of color systems; however, two of the more popular color order systems are Munsell System and Opponent-Colors System.

The Munsell System is a color order system which places objects according to their hue, value, and chroma. The system uses five main hues, red, yellow, green, blue and purple to provide an equally spaced visual hue circle. Value the lightness/darkness parameter, is at the center of the hue circle and has equal visual spacing from 0 (black) to 10 (white). As with hue and value, the chroma term is an equal spacing of color saturation extending from the grays at the center of the hue circle to the strong intense colors situated at the perimeter of the hue circle. Munsell is described as an open color order system; as a result, any color can be designated by Munsell Notation.

An alternate method of describing color is an opponent-colors system based on the complementary approach to color spacing. Opponent-colors systems, in one form or another, are widely used in the plastic industry, to describe an object according to its lightness, redness-greenness (which is positive vector for redder, negative vector for greener), and yellowness-blueness (positive vector for yellower, negative vector for bluer).

The calculation of opponent-colors values are usually the result of spectrophotometric measurements and the manipulations of tristimulus values mentioned later.

## Mathematical Approach Describing Color-A Quantitative Approach

We are now prepared to relate the information about the things we see to quantitative values calculated from mathematical equations utilizing spectrophotometric data.

In review, we have discovered that,

- A. Spectral Energy Distributions have been established for Standard Sources or Illuminants, SED
- B. Objects can be measured, by spectrophotometers, for their spectral curves, reflectance, and transmission (R or T),
- C. Standard observers responses have been calculated for the visual response of a normal population x, y, z, and
- D. A-C, above, is described for all wavelengths of the visible spectrum.

Let us combine the three component response information into Tristimulus Values, X, Y, Z, as follows:

$$k \sum \text{SED} * R * \begin{matrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{matrix} = \begin{matrix} X \\ Y \\ Z \end{matrix}$$

Where:  $k = \frac{100}{\sum \text{SED} * \bar{y}}$ , the normalizing factor, for a perfect white reflecting 100% of the energy across all wavelengths of the visible spectrum.

Tristimulus values are significant building blocks for many calculations in the quantitative description of color, such as: the calculation of chromaticity coordinates, a pinpoint for an object in CIE color space; opponent-type coordinates described earlier; color difference measurements; and a myriad of interactions too numerous to mention here.

The above method is time consuming if done by hand, so modern color measuring instruments have integrated specially designed computer software packages to calculate these values.

A detailed explanation of the color equations is beyond the scope of this paper; however, for further investigation the reader is encouraged to consult the references [1-6].

## Conclusions - Where Do We Go From Here?

Remember the earlier question? Why was the part aquamarine and not sky blue? The answer to the question is not a simple one. The investigator must search for discrepancies which relate to the lighting, the object, and/or the viewing

geometries. As a result, the molder and colorant supplier must use the same materials, lighting condition and mold surfaces, etc., to assure success.

In summary, this paper is by no means an exhaustive investigation into the field of color science, but rather a skimming of the fundamentals of the discipline. To learn more, the reader is invited to participate in active color workshops provided by instrument manufacturers and/or enroll in college and university short courses which will enhance general color knowledge. Colorant suppliers are a ready source of information and are generally willing to assist with specific problems in color measurement. Lastly, develop a working library of research texts [1-6] and practical applications articles [7-13] to assist the struggling enthusiast with problems in color science.