TECHNICAL NEWSLETTER

Coloring of Plastics

Introduction

Color measurement and matching may seem to be simple topics, but they represent some of the greatest challenges and difficulties in the plastics processing industry. Understanding color is more than just picking a Pantone® shade. Getting the appearance of the product or component right is fundamental to getting the product right – it is the first thing a customer sees, and mistakes or errors can result in costly rejects.

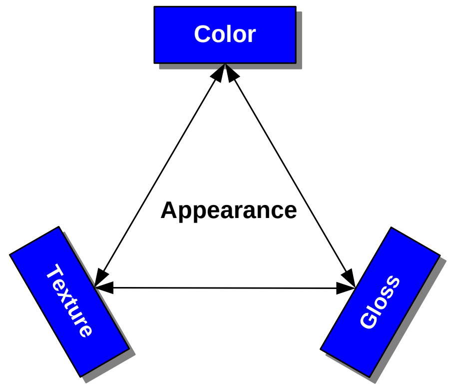
Color is not just visually important. Due to increasing legislation, particularly in the area of heavy metal colorants, the replacement of many traditional colorants with alternatives that have different performance characteristics and processing are being created. Color not only affects our emotional response to a product, it is an emotional subject in its own right.

This newsletter introduces the subject from the basics, points out some of the difficulties, and hopefully makes it all 'crystal clear'.

Appearance

Color is important in any product: It helps us to identify, differentiate, and select components and products. Despite this, the color of any product is really only part of the overall styling and appearance. Color is not the only factor in the general aspect of appearance, as 'appearance engineering' is rapidly becoming an important factor in consumer choice.

The major elements of appearance are shown in the diagram to the right. Surface texture, gloss level, and color are all important in getting the appearance match needed for the product to be acceptable.



Color - Color may be thought of as the 'easy' element of appearance but the definition and measurement of color is not a simple task as will be seen below.

Gloss - Under normal viewing conditions a sample with a high gloss surface will generally appear darker than a sample with a matte surface.

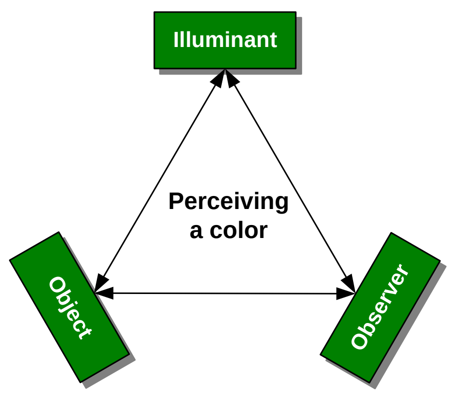
Texture - The surface texture will change the gloss level and affect the perceived color. The human eye is more critical of any color difference in a smooth texture than in a rough texture.

Attempting to find a 'simple' color match can be a frustrating and possibly futile search for the processor and customer because of these other factors. Products of the same nominal color will appear radically different if the other appearance components are not taken into consideration. One of the most frustrating experiences for a designer or engineer is to have the processor 'match' the colors of a range of components manufactured from different materials and then to find that they appear radically different when assembled because of variations in texture or gloss levels in the finished components.

Color – The Fundamentals

Getting the color of a product correct, and more importantly, knowing what you are measuring, requires a basic knowledge of color and how it works for plastics.

Color is not an absolute property as the perceived color of an object is dependent on the three elements shown in the diagram to the right.



Each of the three elements will affect the perceived color:

Illuminant

The illuminant used will affect the perceived color. The perceived color under a fluorescent light is different than that perceived under an incandescent light, and they will both be different to that perceived in daylight. Actually, daylight is one of the most uncontrolled and variable sources of light, and will vary with time of day, weather, orientation, etc. Daylight is not constant! When color matching, the illuminant to be used must always be specified.

Observer

Perception of color requires an observer (either human or instrumental). Every individual has a unique and different sensitivity to color that may be biased slightly towards a specific color. This sensitivity will vary with age and sex, and both perceived colors and color matches will vary with the observer. Color blindness is a genetic trait affecting between 5 - 7% of men and only around 0.5% of women (although they are generally the carriers of the defective X chromosome), where the ability to distinguish between certain colors is poor.

Object

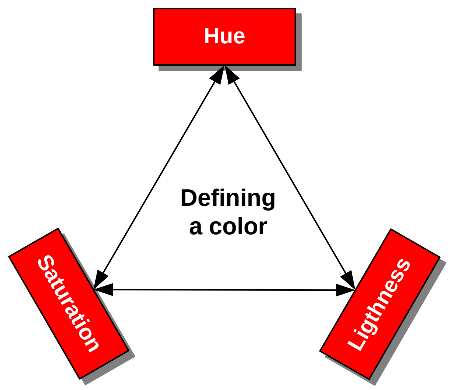
The object may appear to be relatively constant but color perception will vary with the object.

Large areas of color appear brighter than small areas of color (the area effect). Colors will appear duller when in front of a bright background than when in front of a dark background (the contrast effect). Colors will also appear different when viewed from different angles or when illuminated from different angles (the directional effect).

Measuring color

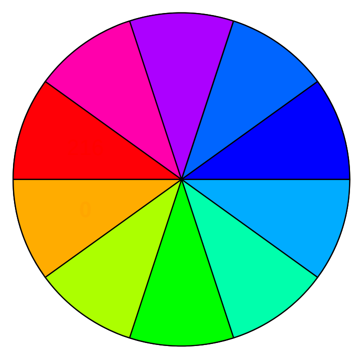
Color measurement can be carried out either by a human colorist or by instrumental means. Using a human provides exceptional differentiation between colors but is limited in how this information can be transmitted to others and used as a control mechanism. Instrumental methods sacrifice some color differentiation, but have the advantage in that they are reproducible and quantitative for comparing and specifying colors.

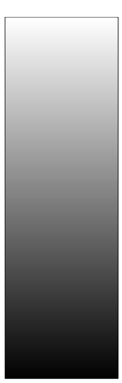
A fundamental requirement of any instrumental color system is that it maps colors onto a 'color space' to provide the numbers or symbols for comparison and specification. All color space systems are concerned with defining three elements (numbers, values, or letters) of a specific color to locate it in a three-dimensional space, and these are shown in the diagram to the right.



Hue

Hue is the basic color and is generally divided into a color wheel ranging through the five principle colors (red, yellow, green, blue, and purple) and all the variations in between. A simple color wheel is shown to the right but the full color wheel shows no distinct transitions between the individual colors. The location of a color around the wheel defines the 'hue' of the color.





Lightness (brightness or value)

Lightness is the vertical axis and runs from light at the top to dark at the bottom. The location of a color on the lightness scale defines how light or dark the color will be.

Saturation (chroma)

The saturation of a color is how far away from the lightness axis it is – colors far away from the value axis are pure colors and those close to the value axis tend to be grayer. Saturation defines how pure a color is.

Various color measurement systems have been developed to locate colors in the three-dimensional space. The first was the Munsell system, developed by the eponymous American artist, Professor Albert Munsell, to describe color in a 'rational way'. The Munsell system defined a three-dimensional polar coordinate for a color such as: 7.5PBYR 6/6: this indicates a purple blue hue tending toward purple with a lightness or value of 6 and a saturation or chroma of 6. This is a purely visual evaluation system but laid the foundations for instrumental color measurement

Instrumental color measurement led to the development by CIE (International Commission on Illumination) of the Yxy color space (based in the XYZ tristimulus values defined by CIE); the L*a*b* color space (CIELAB); and the alternative Hunter Lab color space. In the L*a*b* system the coordinate system is a three-dimensional rectangular system where:

L* defines the lightness/darkness of the color.

a* defines the greenness/redness of the color.

b* defines the yellowness/blueness of the color.

The combination of L*, a* and b* can be used to define the relationship between colors and as a quality control tool. As a result, the system is used extensively in industry for instrumental color measurement.

Color measuring instruments

The two most common types of machines for the measurement of color are the **tristimulus colorimeter** and the **spectrophotometer**.

The **tristimulus colorimeter** directly measures the sample color and uses red, blue, and green receptors in much the same way as the human eye. The colorimeter illuminates the sample with a given light source and measures the light reflected after it passes through red, blue, and green filters. These values are then converted, using a standard formula, to give the color in terms of a standard color space. The major disadvantage with this type of machine is that the results are only meaningful under the specific illuminant used for the machine. Different colorants respond to different lights in different ways [a phenomenon known as metamerism (see below)], and colors that match in one illuminant may not match in another. Unless the colorants used in samples are identical, a tristimulus colorimeter cannot be used for quality control or comparison.

The **spectrophotometer** measures light across the whole of the visible spectrum to produce the full reflectance curve that can be processed to give the tristimulus values and chromaticity for any desired illumination. The full reflectance curve for various colors can be investigated to determine if metamerism will be present under varying illuminants.

The use of spectrophotometers requires knowledge of the type of machine being used and the detailed geometry of the machine – the various types available can detect or exclude texture and gloss levels and even take into account special effect finishes such as mica or flake colorants.

The best information on color measurement is ‘Precise Color Communication’ by Konica Minolta and available free from
http://kmpi.konicaminolta.us/eprise/main/kmpi/content/ContactUs/Contact_PreciseCC

Measurement problems

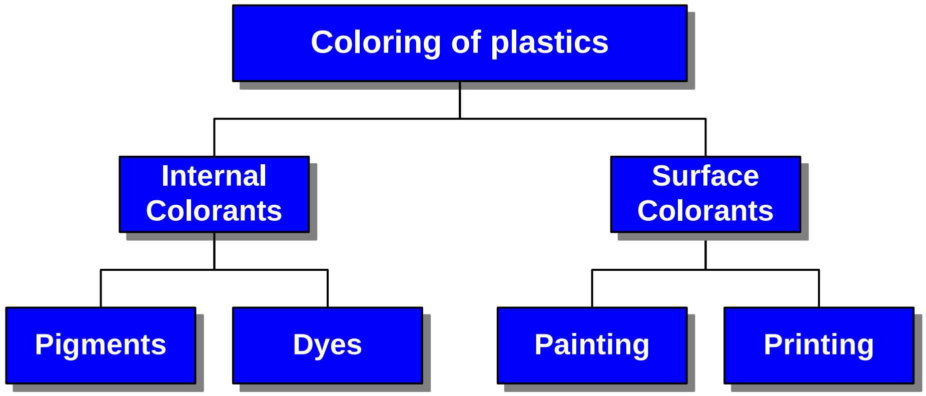
Metamerism: Color perception of many colorants is often affected by metamerism. This is where colors that may appear the same under one set of lighting conditions will appear different under a different set of lighting conditions. This is particularly important when using a simple colorimeter; colors made from varying colorant formulations may show identical tristimulus values under one illuminant and significantly different values under another illuminant.

Temperature: Color is often ‘thermochromic’ and most colors will change with the temperature at which the measurement is made.

Humidity: Color is often ‘hydrochromic’ and most colors will change with the humidity at which the measurement is made.

Methods of Coloring Plastics

Plastics can be colored in many different ways. The chart below shows the main methods:



In this paper we will only consider internal colorants. Surface colorants such as painting and printing have a different set of requirements and concerns and we will hopefully cover these in a future paper.

Internal coloring of plastics can be carried out by the use of either pigments or dyes, and the methods are both fundamentally different and produce different results.

Pigments

Pigments are intensely colored solids that are insoluble in most solvents and in the plastic they are used to color. They are dispersed as discrete particles throughout the plastic and function by absorbing or scattering incident light. Pigments can be inorganic or organic. With translucent pigments, the thickness of the part (or thickness of the tubing wall) may affect the perceived color.

Typical inorganic pigments are manufactured from titanium dioxide (white), carbon black (very black – and don't touch your face after using them!), iron oxides, cadmium compounds, lead chromates, and chromium oxides.

Typical organic pigments are quinacridones (red), phthalocyanines (blue and green), and other complex compounds for a range of colors.

Pigments can only be used for translucent or opaque colors. Inorganic pigments have high heat and light stability and are very economic to use. Organic pigments tend to be stronger than the inorganic pigments, but the heat and light stability of organic pigments varies with the particular pigment used.

Dyes

Dyes are organic liquids that are soluble in most solvents and in the plastic they are used to color. They are generally 'strong' colors and have good transparency, which means they have very little effect on the light transmission through the colored plastic. Dyes are generally in liquid form and are very easy to disperse in most polymers. They are generally used when a transparent product is needed due to their light transmission properties.

The choice of the exact pigment or dye to use is a complex one and depends on the plastic being colored, the processing method, and the specific application (particularly if it is an external application).

Processing and color

Delivery of the color to the basic plastic before processing can be via masterbatch, dry color, liquid color, or by color concentrates. The precise delivery method chosen depends on the process, the length of the run, and the product requirements.

The perceived color with a plastic product also depends on the processing of the plastic during production. Processing must be sufficient to adequately and uniformly disperse the selected color, and yet not so much as to affect the color appearance through excessive thermal history or shearing of the plastic or the colorant system. Colorants can easily be affected by the thermal history during processing to give unstable color results. Shearing of the plastics is a necessity for most plastics processing, but excessive shearing can break pigments into smaller particles and affect their perceived color.

Pigments particularly should always be tested in the plastic and process that they will be ultimately used in to avoid color shifts caused by processing.

Legislation

Throughout the world there is increasing legislation (such as RoHS – see the previous paper on this topic) to reduce and restrict the use of heavy metals such as lead (Pb) and cadmium (Cd) in all products. Both lead and cadmium compounds have been used extensively as pigments in the past because of their brilliant colors, excellent heat and light stability, long life, low metamerism properties, and low cost. The cadmium compounds were particularly effective for reds, yellows, oranges, and purples, and the lead chromates and lead molybdates were excellent for oranges.

The legislation is driving the replacement of these materials with alternative non-heavy metal replacements for most applications. The development of replacement pigments has been rapid and largely successful, but in some cases there has been difficulties in matching the performance of the Pb and Cd-based materials in terms of brilliance and longevity.

While the desire to remove hazardous substance from the workplace and the environment is to be supported, the colorants involved are firmly locked into the plastic matrix and are not free to migrate into the general environment.

Studies in injection molding factories have shown that workers using plastics containing Cd pigments were not exposed to concentrations above the regulatory levels[1]. If disposal takes place by landfill, the bioavailability of the colorant is so low that the heavy metals are not expected to be present in any landfill leachate[2]. If disposal is by incineration then the current controls on air pollution and ash disposal will prevent release of the heavy metals into the environment.

Despite this, the restriction and removal of Cd and Pb-based colorants will undoubtedly continue to be required by legislation and processors should be aware of the requirements to replace these products with more ‘environmentally friendly’ products in the future.

Summary

Color can be a vital part of a design, for part identification and organization; however, color and appearance are not the simple subjects that they initially seem to be. There is no such thing as a ‘simple’ color match. The concepts of appearance as a general feature, the idea of color as being a ‘perception’-based phenomenon that is difficult to quantify and measure, and the rising tide of legislation, all make coloring of plastics a difficult and error-prone field. With all of that said, armed with the information from this Newsletter you will be better able to "speak the language of color" and communicate more effectively with your processor. Go ahead – colorize!

[1] J. Bonilla and R. Milbrath, “Cadmium in Plastic Processing Fumes From Injection Molding”, American Industrial Hygiene Association Journal, Vol.55, 1994.

[2] “Heavy Metals in Packaging”, California Integrated Waste Management Board (1994).

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