Plastics Topics – Colouring of plastics

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1. Introduction

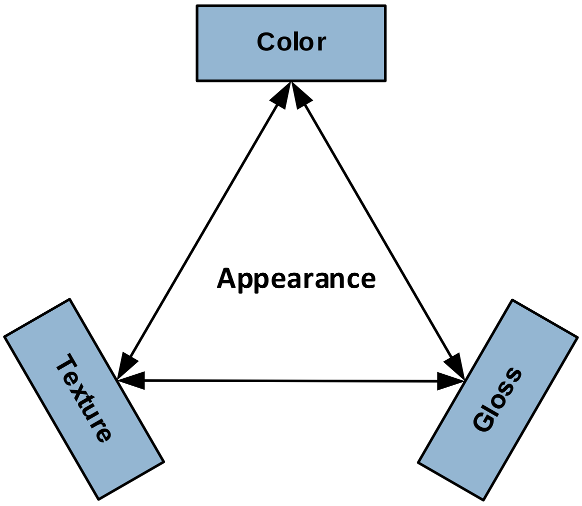
Colour measurement and matching may seem to be simple topics they but represent one of the greatest challenges and difficulties in the plastics processing industry. Getting the appearance of the product or component right is a fundamental to getting the product right – it is the first thing a customer sees and mistakes or errors can result in costly rejects. Colour and appearance can often determine if a processor makes a profit or not.

Colour is not only visually important but increasing legislation, particularly in the area of heavy metal colorants, is driving the replacement of many traditional colorants with alternatives that have different performance characteristics and require different processing. Colour not only affects our emotional response to a product it is also an emotional subject in its own right.

2. Appearance

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

The major elements of appearance are shown in the diagram (below) and surface texture, gloss level and colour are all important in getting the appearance match needed for the product to be acceptable.



The elements of 'appearance'

Colour

Colour may be thought of as the 'easy' element of appearance but the definition and measurement of colour is not a simple task.

Gloss

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

Texture

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

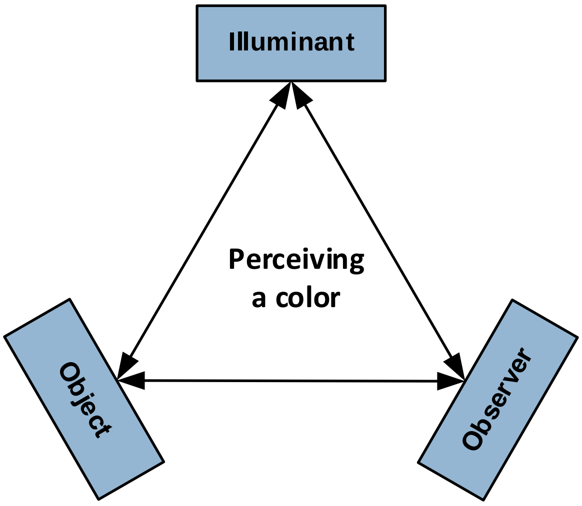
Attempting to find a 'simple' colour match can be a frustrating and possibly futile search for the processor and customer because of these other factors. Products of the same nominal colour will appear radically different if the other appearance components are not either matched or allowed for. One of the most frustrating experiences for a designer is to have the processor 'match' the colours 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.

3. Colour

The fundamentals

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

Colour is not an absolute property and the perceived colour of an object depends on the three elements shown in the diagram below:



The elements of perceived colour

Each of the three elements will affect the perceived colour:

Illuminant

The illuminant used will affect the perceived colour. The perceived colour under a fluorescent light is different to that perceived under an incandescent light and they will both be different to that perceived under daylight. 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 colour matching the illuminant to be used must always be specified.

Observer

Perception of colour requires an observer (either human or instrumental). Every individual has a unique and different sensitivity to colour that may be biased slightly towards a specific colour. This sensitivity will change with age and sex and both perceived colours and colour matches will vary with the observer. Colour blindness is a genetic trait affecting between 5 and 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 colours is poor.

Object

The object may appear to be relatively constant but colour perception will vary with the object. Large areas of colour appear brighter than small areas of colour (the area effect). Colours will appear duller when in front of a bright background than when in front of a dark background (the contrast effect). Colours will also appear different when viewed from different angles or when illuminated from different angles (the directional effect).

4. Measuring colour

Colour measurement can be carried out either by a human colourist or by instrumental means. Using a human provides exceptional differentiation between colours but is limited in how this information can be transmitted to others and used as a control mechanism, instrumental methods sacrifice some colour differentiation but have the advantage that they are reproducible and produce numbers that can be used to compare and specify colours.

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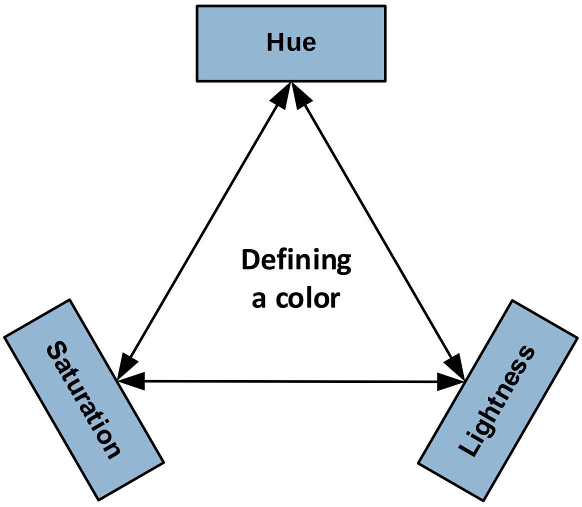
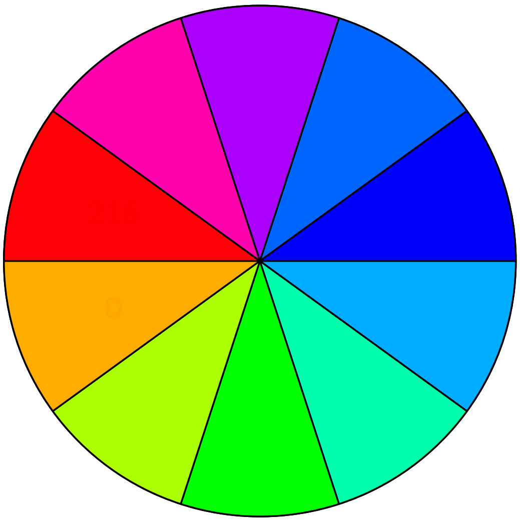
A fundamental requirement of any instrumental colour system is that it maps colours onto a 'colour space' to provide the numbers or symbols for comparison and specification. All colour space systems are concerned with defining three elements (numbers, values or letters) of a specific colour to locate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



The elements of a colour definition

Hue

Hue is the basic colour and is generally divided into a colour wheel going through the five principal colours (red, yellow, green, blue, and purple) and all the variations in between. A simple colour wheel is shown below but the full colour wheel shows no distinct transitions between the individual colours. The location of a colour around the wheel defines the 'hue' of the colour.



A simple colour wheel

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 colour on the lightness scale defines how light or dark the colour is.

Changing lightness

Saturation (chroma)

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

Changing saturation

Various colour measurement systems have been developed to locate colours in the three-dimensional space and the first was the Munsell system, developed by the eponymous American artist, Professor Albert Munsell, to describe colour in a 'rational way'. The Munsell system defined a three-dimensional polar coordinate for a colour 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 colour measurement.

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

- L* defines the lightness/darkness of the colour.
- a* defines the greenness/redness of the colour.
- b* defines the yellowness/blueness of the colour

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

5. Colour measuring instruments

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

The tristimulus colorimeter directly measures the sample colour 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 standard formulae, to give the colour in terms of a standard colour 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 colours that match in one illuminant may not match in another. Unless the colorants used in samples are identical then 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 colours 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 colour measurement is 'Precise Colour Communication' by Konica Minolta and available free from https://www.konicaminolta.com/instruments/knowledge/color/pdf/color_communication.pdf.

Measurement problems

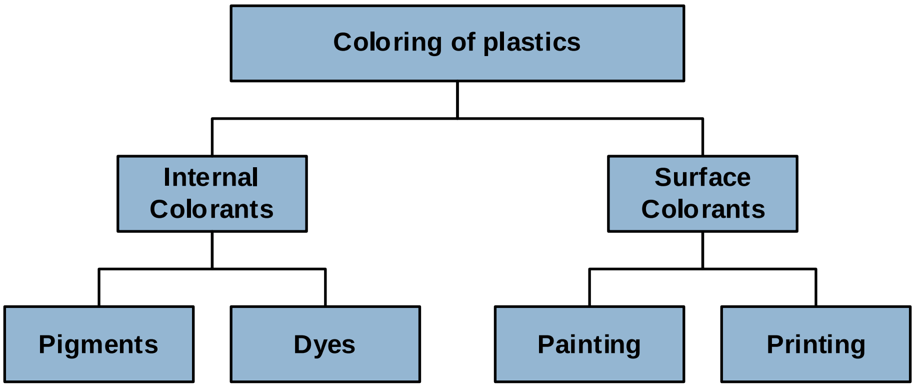
Metamerism: Colour perception of many colorants is often affected by metamerism, this is where colours that may appear the same under one set of lighting conditions will appear different under a different set of lighting conditions. This is particularly important when using a simple colorimeter; colours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

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

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

6. Plastics

Plastics can be coloured in many different ways and the chart below shows the main methods:



The methods of colouring plastics

In this article we will only consider internal colorants, surface colorants such as painting and printing have a different set of requirements and concerns.

Internal colouring 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 coloured solids that are insoluble in most solvents and in the plastic they are used to colour. They are dispersed as discrete particles throughout the plastic and function by absorbing or scattering incident light. Pigments can be inorganic or organic.

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 colours.

Pigments can only be used for translucent or opaque colours. 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 colour. They are generally ‘strong’ colours and have good transparency, which means they have very little effect on the light transmission through the coloured 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 coloured, the processing method, the specific application (particularly if it is an external application).

7. Processing and colour

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

The perceived colour 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 colour and yet not so much as to affect the colour 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 colour 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 colour.

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

8. Legislation

Throughout the world there is increasing legislation (such as RoHS) to reduce and restrict the use of heavy metals such as lead (Pb) and cadmium (Cd) in all products. Both lead and cadmium compounds were used extensively in the past as pigments because of their brilliant colours, 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.

Legislation has driven 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 have been difficulties in matching the performance of the Pb and Cd based materials in terms of brilliance and longevity.

Whilst 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.

9. Summary

Colour and appearance are not the simple subjects that they initially seem to be. A ‘simple’ colour match is no such thing. The concepts of appearance as a general feature, the idea of colour as being ‘perception’ based phenomenon that is difficult to quantify and measure and the rising tide of legislation make colouring of plastics a difficult and error prone field. Hopefully, after reading this, the potential pitfalls will be clearer and there will be more sympathy for the processor who has to deal with a colour match that is ‘not quite right’.