5.1 Introduction to Colour

Colour is an essential ingredient of consumer products especially those made from plastics. There are very few industries today in which colour does not play a major role. Originally colour was used for masking the natural coloration or discoloration of thermoset resins. This function has now decreased in importance with the availability of essentially colourless thermoplastics.

The colouration of plastics is not only an essential tool for sales promotion but is also an important factor in product design. The increased scale of production and assembly line operations of the industries using coloured plastic components has necessitated tighter control of colour from standard to batch, and from batch to batch. This in turn has brought about the need for some form of instrumentation in plastics colouring operations and colour measurement.

5.2 What is Colour ?

Colour is only one part of the much larger subject of appearance, i.e. the way things look. Apart from colour there are many factors that may influence the appearance of an object, such as opacity or transparency, gloss or mattness, surface texture, i.e., embossed or smooth and metallic reflection or diffusing surfaces. If these factors are removed what remains is absorption of light by the object in such a way that some colours are removed from the light and some are reflected or transmitted. The colour we see in an object however is not in the object but in our brains. Colour is our brain's perception of light that has been modified by the absorption of part of its rays.

5.3 Visual Perception of Colour

There are three factors that determine the visual perception of an object.

(1) light source;
(2) sample;
(3) observer.

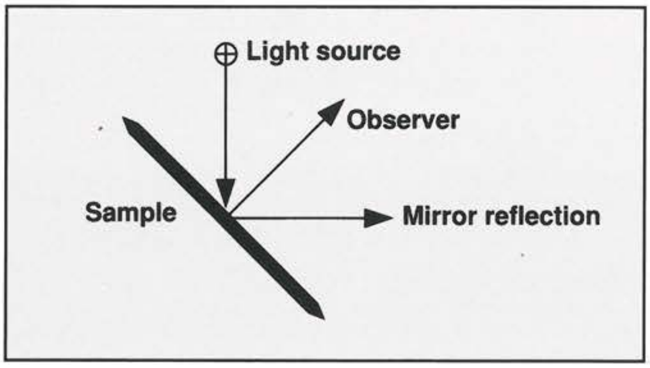

Fig. 5.1: **Factors resulting in colour perception.**

Light Source

Light is the electromagnetic radiation that also includes for example X-rays, ultraviolet and infrared radiation. All these types of radiation are described either by the frequency (cycles per second) or the wavelength of one cycle. The wavelength of light is usually expressed in *nanometres*, nm; (1 nm = 10^{-9} m). The human eye can respond to electromagnetic radiation between 380 nm and 780 nm as light. Light with a short wavelength appears blue - as the wavelength increases the colour appears to change through green, yellow and orange to red. Radiation combining all the wavelengths of the visible spectrum in almost equal proportions is perceived as white light.

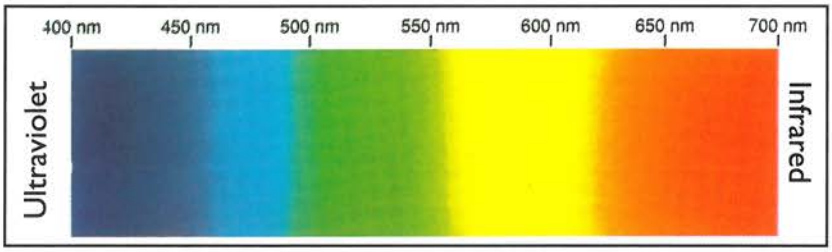

Fig. 5.2: **The spectrum of visible light**

Radiation with a wavelength lower than 400 nm is called *ultraviolet light*. This type of light not only tans or burns the skin, but is also responsible for damaging many plastics, either the basic material or the colourants that have been added. Radiation with a wavelength greater than 700 nm is classified as *infrared light* and is perceived as thermal radiation.

We all know from everyday experience that a coloured object looks different in the sunlight, under cloudy skies, under fluorescent light or under a normal electric light bulb. It is therefore important to select a light source before defining colour tolerances both for visual assessment or in colourimetry. Colour assessment should be carried out in a colour assessment booth where the light source can be selected.

Samples

Samples generally can be divided into three categories:

(a) non-transparent (opaque reflective) samples;
(b) transparent;
(c) translucent.

(a) *Non-transparent (opaque reflective) samples*
Some light is reflected and some is absorbed but no light passes through such samples.

(b) *Transparent Samples*
These samples allow light to pass through essentially unchanged. However, at every boundary between two different materials such as an air-plastic interface, light changes its speed and as a result a small fraction of the light is reflected.

(c) *Translucent Samples*
In addition to being transmitted and reflected light may also be absorbed. In translucent samples some of the light is absorbed, some passes through the sample unscattered (transmitted) and some is scattered.

When comparing samples visually, e.g., standard to colour match, the samples should have at least one straight edge. This is essential as colours can only be assessed accurately by laying the standard and the reference side by side. It is also important to eliminate the *mirror gloss effect* for samples with a smooth gloss surface. This can be done by holding the samples at a 45° angle to the incident light. A small stand angled at 45° is useful for this purpose.

Samples should also have the same surface finish. It is impossible to assess accurately colour if one sample has a smooth gloss surface and the other has a textured surface.

Observer

In the case of visual assessment the observer is the human eye. If colourimetry is used then the observer is the instrument receiver.

Today there is instrumentation available that can numerically describe visual colour and colour difference. The observed differences in colour between two objects can be described in terms of three variables. These are called colour co-ordinates and form the basis of the language system most widely used in colour description and specification. These variables are known as *Hue, Chroma* and *Value*.

(a) *Hue*
This is the term used to distinguish the difference between two isolated colours, e.g., red, green, purple, beige, etc. The total number of hues that can be distinguished is very large but of these only four are unique. These are: red, yellow, green and blue. All other hues are a combination of two of these four with the restriction that it is not possible to have a hue that is a mixture of blue and yellow or of red and green. With these pairs eliminated as mixtures, the remaining pairs can be arranged in a continuous circle.

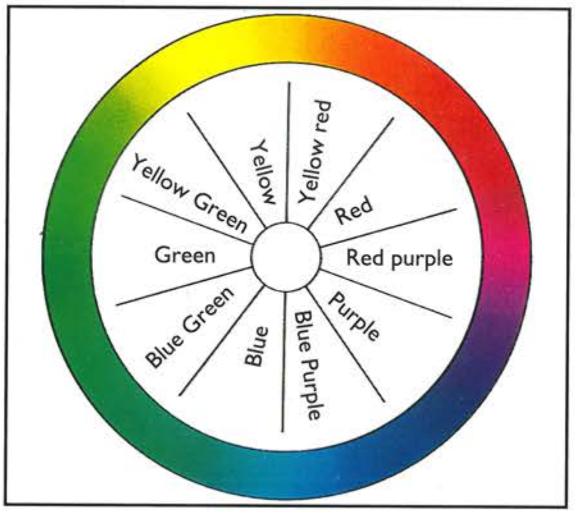

Fig. 5.3: **Colour wheel**

(b) *Chroma or saturation*

A second difference between two colours of the same or different hue is the amount of hue seen. This variable is saturation or depth of colour, it is vivid or dull. There is no well defined upper limit to saturation in colour but there is a zero saturation, at which point there is no hue perception. Since hues can be arranged in a circle and saturation (chroma) starts at zero and increases, the two can be combined in a circle diagram with zero at the centre.

(c) *Value or Brightness*

The third difference between two isolated colours is brightness. A colour can vary from being too dim to be seen, to being too bright to look at. Except for difficulties in producing it, as far as perception is concerned, such a change can occur for any hue at any saturation (chroma). If we combine the circle diagram (Figure 5.3) with a vertical axis of value (brightness) it gives us a three-dimensional system by which we can describe colour.

Hue, value and chroma are the three colour characteristics and can be visualised in three dimensions as shown in figure 5.4. Colour hues are around the centre axis with value forming the vertical axis, and chroma the horizontal axis.

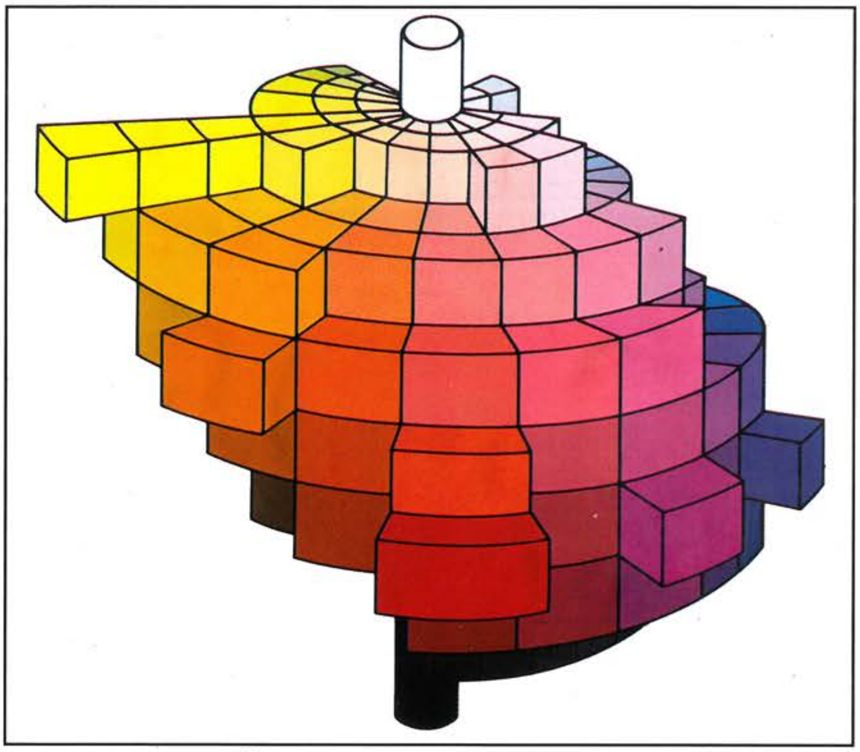

Fig. 5.4: **Colour Solid**

In 1976 the C.I.E. (Commission International de l'Eclairage) decided to recommend two colour difference formulas for world-wide use. The one recommended for normal reflective or transparent samples is known as the CIELAB formula.

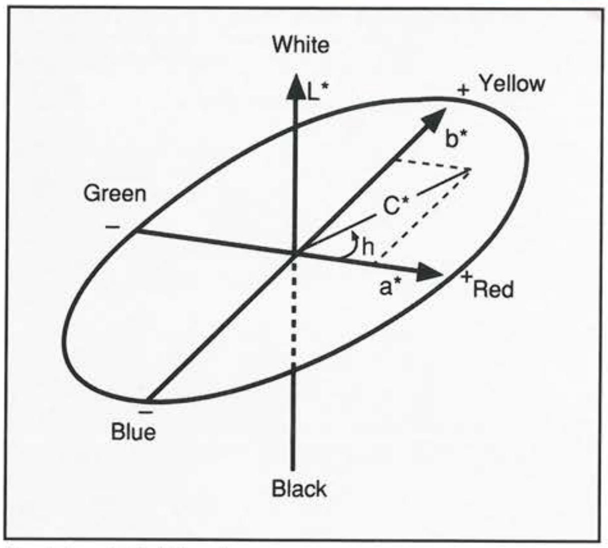

Fig. 5.5: **CIELAB colour system**

The CIE colour space is described by L,a and b where:

- L corresponds to the Light/Dark axis.
- a corresponds to the Red/Green axis.
- b corresponds to the Yellow/Blue axis.

The total colour difference between the standard and the sample in the colour space is referred to as Delta E (ΔE).

However this does not describe in which direction the difference lies. To determine the difference in direction, values for L, a and b are obtained for the standard (1), and the samples (2), and are calculated as follows:

$$\Delta L = L_1 - L_2$$

where a positive value indicates that the sample is lighter than the standard and a negative value indicates that the sample is darker than the standard;

$$\Delta a = a_1 - a_2$$

where a positive value that the sample is redder than the standard and a negative value indicates that the sample is greener than the standard;

$$\Delta b = b_1 - b_2$$

where a positive value indicates that the sample is yellower than the sample and a negative value indicates that the sample is bluer that the standard.

The total colour difference is calculated using the formula :

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

5.4 Metamerism

Metamerism is simply described as the colour of two samples appearing identical under one light source but different under another light source. It is a problem which can be impossible for colourists to resolve. Metamerism can only occur if the colourants used in the standard and the sample are different. This can very often occur if for example polystyrene, PVC and ABS are matched to the same colour. This is because colourants used to colour PVC may not be suitable to colour polystyrene or ABS. This results in different colourants being used and thus metamerism.