Characterization of gonio-apparent colours

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ABSTRACT

The characterization of gonio-apparent materials[1, 2] which change colour according to the illumination and viewing angle, is not straight forward. In our laboratory, a goniospectrophotometer was built to measure the absolute Bidirectional Scatter Distribution Function (BSDF) of an object at almost any geometry. Different test measurements are executed. ChromaFlair® samples are characterized at a specific angle of illumination (45°) and many viewing angles. It is shown that the very limited range of viewing angles as proposed by a DIN standard is not sufficient for a full description of this kind of material. New methods are needed to represent the large amount of BSDF data that can be generated from a goniospectrophotometric instrument.

1. INTRODUCTION

When an object is illuminated, the incident light will be reflected, transmitted, refracted, absorbed and scattered. These optical processes are responsible for the optical properties of the material, which can be divided into four categories: colour (spectral information), gloss (spatial information), translucency and surface texture. It is recognised that these measures are not necessarily independent, which is one of the main difficulties to characterize the overall appearance of an object.

To expedite a colour measurement process, the CIE has recommended two basic systems of geometry that are usually implemented in colour measuring instruments. These are known as 45/0 geometry and d/8 geometry[3].

There are, however, many surfaces that cannot be adequately measured using such limited conditions – the so-called gonio-apparent or special-effect colours. A popular example is the often coloured, metallic finish, applied to many automobiles.

Gonio-apparent materials, which change colour according to the angle of illumination and viewing, have rapidly grown in popularity over the last 50 years. Nowadays, dramatic colour effects can be achieved. There are no standard geometries and no internationally accepted methods for assessing colour variations of gonio-apparent materials[4]. For a complete characterization of such objects, one has to measure the colour at more than one illumination/viewing angle combination. This has been partly overcome by the introduction of so called multi-angle spectrophotometers, which measure at more than one, and typically at four or five viewing angles as proposed by DIN 6175-2[5]. However, for many surfaces, notably some of the pearlescent and interference pigments that are now being used for product finishes, the use of more measurement/illumination angles becomes necessary. A colour measurement procedure is needed which can meaningfully characterize such colour effects.

In our laboratory, we have built a goniospectrophotometer which allows us to determine the absolute Bidirectional Scatter Distribution Function (BSDF) of an object at almost any geometry. Spectral properties can be measured at any angle of illumination and over a much larger range of viewing angles compared to the classical multi-angle spectrophotometers. In this paper we describe our goniospectrophotometer and report on angular resolved spectral measurements made using a ChromaFlair® sample[6], a material which shows very dramatic colour effects. It is clear that more, and/or different, viewing angles than those proposed in the standard are needed in order to characterize the colour of such materials at one angle of incidence.

2. METHOD

The absolute goniospectrophotometer allows us to measure the absolute Bidirectional Scatter Distribution Function (BSDF). A 300W Xe light source is used for the illumination of the specimen (Muller GmbH Elektronik-Optik, SVX1530 + XM300-HS). Having large emission intensities in the blue-violet region of the visual spectrum, a good signal to noise ratio can be achieved over the whole visible spectrum. The detector head consist of a lens and a very small integrating sphere which is coupled to a spectrometer/CCD detection system (Oriel MS125 spectrograph and Oriel INSTASPEC IV CCD) with a quartz fiber. The diameter of the lens is 20mm. The distance from the specimen to the detector head is 750 mm. The use of an automated filter-wheel carrying three neutral density filters extents the dynamic range to 6 decades. While measuring the dark current, the incident light beam is directed to a silicon photodiode. The response of this detector allows us to compensate for the fluctuations in the light source output. As we measure the incident power on the sample with the same detector head, absolute BSDF-values can be calculated from both dark current corrected CCD readings (counts) according to ASTM E1392[2].

ChromaFlair®[6] is a material that shows dramatic colour effects. It consists of small flakes (thickness in the order of 1µm) which are built up of a highly transparent layer on an opaque reflecting metal and covered by a semi-transparent absorber[7]. The dependency of colour on the viewing angle originates from interference of the light in the transparent layer and from selective absorption in the top layer.

Several standard colours are currently available. A typical colour name is for example "Red/Gold 000"[8]. The name reflects the colours seen at approximately 0° and 45° respectively. The number represents the pigment's approximate hue at the normal viewing angle.

3. RESULTS

Some test and reference measurements were performed on our instrument. At first, we checked the stability and reproducibility of the measurements. The flux of the incident beam of light was observed during a time interval of one hour. Fluctuations of 3% were measured. Using the compensation method described above however, the fluctuations of the corrected incident beam flux are reduced to 1% or less.

Secondly we acquired the instrument function. The detector head was placed in the zero angle position with no sample mounted. The detector head, the sample holder and the light source are then collinear. The detector head is scanned through the incident beam and the response measured at different viewing angles is recorded. The radius of the incident light spot at the detector plane is smaller than the aperture of the detector head. Consequently, a constant flux value was measured at viewing angles below 0.3°. Beyond 0.3°, the response diminishes gradually until the detector head misses the incident light beam completely. Making use of the neutral density filters and the CCD readout integration time, we have obtained a dynamic range exceeding six decades.

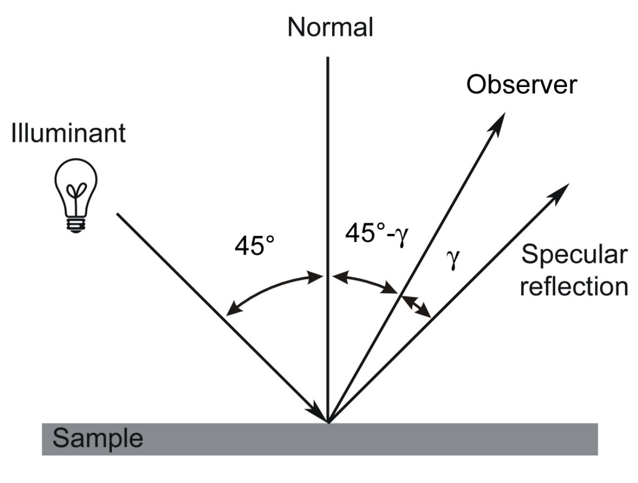

Figure 1: Measurement geometry. Viewing angle γ is referred to the specular reflection ('Effektwinkel').

Reference measurements on specular and Lambertian reflecting samples, and on dichroic filters in reflection and transmission mode, completed our preliminary tests.

We performed measurements of the spectral BRDF, $q_{e,\lambda}$, on ChromaFlair® samples. In agreement with the DIN standard, the angle of incidence was taken as 45°. The viewing angle γ is expressed in terms of the 'Effektwinkel'[5] or

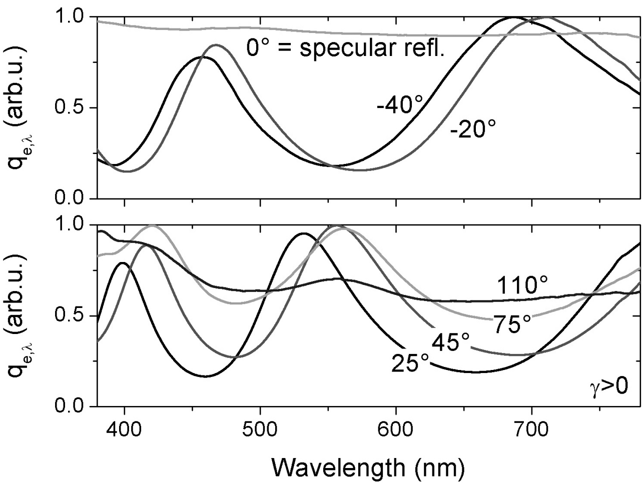

Figure 2: Measurement of spectral BRDF $q_{e,\lambda}$ at different viewing angles performed on the ChromaFlair® SilverGreen060. A (upper): γ=0°, -20°, -40°; B (lower): viewing angles according to DIN standard.

aspecular angle, i.e. the angle referred to the specular reflection angle (see Figure 1). γ is taken to be positive towards the incident light direction and negative away from it, in agreement with the DIN 6175-2 standard. Colorimetric quantities are calculated for the CIE Standard Illuminant D65 and the CIE 10° Standard Observer.

The spectral BRDF, $q_{e,\lambda}$, of a sample called "SilverGreen060" is shown in Figure 2A. The interference patterns induced by the ChromaFlair® flakes are clearly observed. In Figure 2B, the shift in the spectral behaviour of $q_{e,\lambda}$ for the viewing angles mentioned in the DIN standard is illustrated: the larger the viewing angle, the smaller the differences between the minima and maxima of the interference pattern.

The DIN standard does not include measurements at negative viewing angles. From Figure 2A however, an important colour shift can be expected at these angles. Similar results are obtained on other ChromaFlair® samples. In the specular direction, the external reflection dominates; resulting in a BRDF which is nearly wavelength independent and the actual colour of the sample becomes 'white'.

Figure 3 shows the L*a*b* colour coordinates calculated from the spectral values. Viewing angles ranged from γ = -40° to γ = 125° with a 5° angle interval in the direction indicated by the arrow. The DIN standard (relying on the work of Alman[9]) suggests measuring at angles γ = 25°, γ = 45°, γ = 75°, γ = 110°. It is clear that these values are covering only a very small region of the potential colour shifts. Moreover, it seems that colour changes beyond γ = 45° are rather irrelevant. However, the colour shift for negative viewing angles is more impressive. It is clear from these measurements that the standard viewing angles are not sufficient to characterize these kinds of materials.

We are further illustrating the shortcomings of the DIN standard in Figure 4. The DIN standard angles are marked by arrows. At large viewing angles, the chromaticity and the chromaticity change drop to zero, indicating an unsaturated, near-neutral colour. At angles below γ = 25° the chromaticity remains high, indicating strong saturated colours at these viewing angles. These angles should also be considered, when characterizing this kind of material.

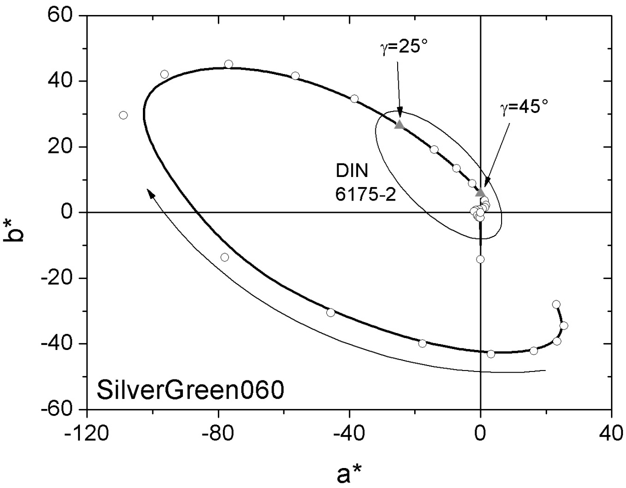

Figure 3: L*a*b* colour coordinates of ChromaFlair® SilverGreen060. Viewing angles ranged from γ = -40° to γ = 125° with a 5° angle interval in the direction indicated by the arrow. The angle of illumination was 45°. The ellips isolates the region defined by the DIN standard.

4. DISCUSSION

When measuring gonio-apparent colours, questions regarding the illumination and viewing angles arise. Over the past few years, the standardisation of the measurement of gonio-apparent colours has been investigated. Gabel[10] stated that an instrument using a single illumination or a single viewing angle is not sufficient to fully characterize the colour effects of gonio-apparent materials. The DIN 6175-2 standard has already been mentioned [5, 9].

Flex Products[8] proposes the near specular multi-angle geometry. In this method, a fixed aspecular viewing angle is proposed at illumination angles varying from 10° to 60° in 5° increment. From these results, a Dynamic Colour Area Diagram is generated and the DCA-metric is used to quantify the colour travel of the pigment. Negative viewing angles are not taken into consideration.

Nadal and Germer of NIST[11] suggested a new colour measurement instrument, for example with three illumination angles and five viewing angles.

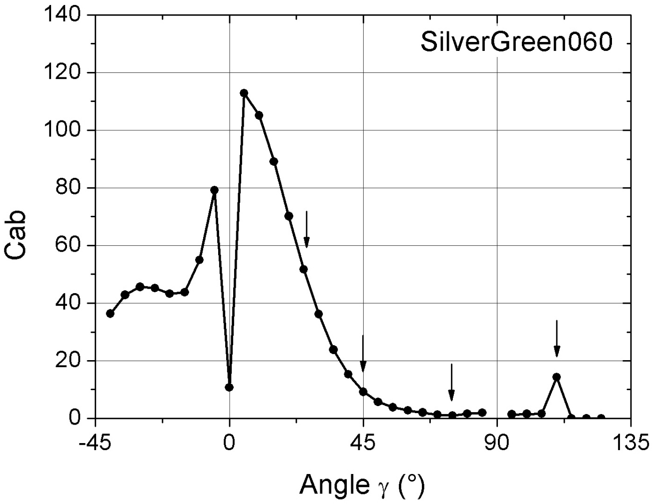

Figure 4: Chromaticity as function of viewing angle γ. The angles recommended in the DIN standard are marked with arrows.

5. CONCLUSIONS

In this paper, we measured spectral BRDF on ChromaFlair® pigments. According to the DIN standard, we restricted the illumination angle to 45°. We observed an important colour shift and strong saturated colours beyond the range of viewing angles proposed by the standard, particularly for viewing angles below the specular reflection. As far as we know, this effect has not been reported before.

We suggest extending the range of viewing angles to be measured with at least one, perhaps two negative viewing angles. Referring to Nadal and Germer[11], measurements will be performed in the near future to investigate how many illumination angles have to be taken into account to obtain a full characterization of these materials.

References

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