Brightness and sparkle appearance of goniochromatic samples

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Abstract

*In 2013 the European Metrology Research Program (EMRP) funded the research project, "Multidimensional Reflectometry for industry, xD-Reflect", to investigate the macroscopic optical properties related to visual appearance of modern surfaces and to develop and improve methodologies, tools and measurement devices able to provide a better description of material characteristics. One of the planned task developed several subjective tests on visual descriptors of gloss, sparkle, graininess, colour and their combined influences with reference to the measured values of reference samples. INRIM performed investigation on subjective descriptors of brightness and sparkle and their relationship with geometrical conditions of view, illuminating source characteristics, measured Radiometric Bidirectional Reflectance Distribution Function (BRDF), colorimetric attributes (CIE L*a*b*) and sparkles. This paper deals with the definition of subjective Brightness and Sparkle scales considering achromatic samples of goniochromatic materials, under LED and not LED lighting source. Key points of this study are the use of a soft metrology approach, with strong metrological characterization of the test behaviour (i.e. radiance and illuminance distribution, BRDF and sparkles of the samples), and the use of a large subject group (about 100 subject attended the test).*

Introduction

The appearance of an object surface is one of the most critical parameters to be measured; it depends on several factors, including the observer. The measurement of appearance [1], or more in general of a quantity expressing the human response to external stimuli, is nowadays of great interest in metrology and its related to many industrial applications. CIE [2] defines the Appearance as "*the visual sensation through which an object is perceived to have attributes as size, shape, colour, texture, gloss, transparency, opacity etc.",* while Total Appearance "*points out the visual aspects of objects and scenes"* and arises from the combination of colorimetric (hue, saturation, brightness) and geometric (gloss, sparkle, texture, shape,…) material properties and the influence of environmental conditions (attributes like illuminance, source spectrum, background,…) with the observer behavior (visual adaptation, condition of view, expectations,…).

Actually visual evaluation and appearance are considered key parameters in customer satisfaction: products appeal according to their appearance. The ability of measuring and reproducing material appearance, with the assurance of metrology principles (measurand definition, reproducibility, accuracy), can affect also the industrial competitiveness [3] and is one of the reasons that the European Metrology Research Program (EMRP) [4] funded the Joint Research Project "Multidimensional Reflectometry for industry, xD-Reflect" (JRP xD-Reflect) [5].

The aims of JRP xD-Reflect are 1) to investigate the optical properties related to visual appearance of modern surfaces that, having strong angular dependent reflection behaviors, need to be characterized by multidimensional reflectometry, 2) to improve the European measurement capabilities, through the definition of relevant measurement and calibration methodology, the reduction of measurement uncertainty, the identification of relevant measurement geometries, the development of transfer standards; 3) to increase the comprehension of subjective and objective aspects of the visual attribute and the correlation with materials characteristics and environmental attributes [6].

Measuring the total appearance of an object or of a scene, is a very complex exercise [7] and its definition, measurement and mathematical description are not in the aims of the Joint Research Project. Instead the adopted approach considers the improvement of the optical characterization of material surfaces considering quantitative parameters strongly correlated to visual appearance, and, if necessary, developing new or improved definition of the available quantities. Therefore, the appearance evaluation planned in JRP xD-reflect, focus on modern materials with goniometric behaviour (characterised trough multidimensional reflectometry), on gloss, colour, sparkle and environmental influences.

Current methodologies for materials characterization are not able to accurately predict visual perception of these new materials, because these are based on methods and measurable quantities developed considering reference materials (usually ceramic tiles for color reference or dark glass for gloss reference) with simple optical behavior. The modern materials, with sophisticate visual effects such as goniochromatism, deep matt finishes, sparkle and metallic effects, high gloss, stress the applicability of actual measurement methods for the real characterization of their appearance. New lighting technologies such as LED point sources make more difficult predicting colour perception, difference evaluation and material appearance in general.

These modern materials are usually characterized using Gonio-reflectometers. They are very expensive devices, not so common in industrial labs, able to acquire the reflected (or transmitted) radiation from a sample for every direction of incidence, in every direction of view. Industrial labs are instead equipped with portable measurement instruments, usually able to measure the radiation reflected toward few directions from one single direction of lighting incidence. These devices have been developed for the industrial community, to meet the demand of production and control quality, as requested by ASTM [8] [9] [10] and DIN [11] standards on multi-angle color measurements for metallic or interferential finishes.

The directions of view haven't been defined on the base of peculiar constraints, but are an evolution of CIE recognized standard configuration for directional reflectance analysis (formerly 45°/0°). In fact only two standardized geometrical conditions are recognized by CIE for colour measurements: d/0 (diffuse irradiation and detection at 0° or 8°) and 45/0 (directional irradiation under 45° and detection at 0° or 8°). Industrial instruments for appearance measurements (i.e. multi-angles measurement devices) consider other angular conditions for characterizing special features of gonio-apparent materials (i.e. materials with change in appearance with change in illumination or viewing angles) [12]. These angular conditions are defined in standards [8] [9] [10] [11]as: Near specular angle (called

45:15, 45° incidence, view 30° from the normal in the reflection semi space), Mid specular angle (45:45, 45° incidence, view 0°) and Far specular angle (45:110, 45° incidence, view 65° from the normal in the incidence semi space). Additional angles in portable multi-angle measuring instruments are 45:25 (45° incidence, view 20° from the normal in the reflection semi space), 45:75 (45° incidence, view 30° from the normal in the incidence semi space) and other depending on the instruments considered.

The following points shall be considered in developing the subjective investigations:

- ASTM [9] states that measurement results of 45:25 may occasionally not agree with visual perception.
- To ensure appropriate appearance measurements, Eugène [1] suggests to fix specific conditions of test and product characteristic because appearance is a multidimensional measurement process related to several factors.
- When LED lighting is involved the prediction of the models adopted in lighting engineering doesn't fit well (like Colour Difference Formula and Colour Rendering Index) [13 [14 [15] [16].

Subjective investigations

Subjective investigations, presented in this paper, are performed following the "soft metrology" approach [17] [18].

Soft metrology was a concept first introduced by M.R. Pointer in an NPL (National Physical Laboratory) report in 2003 [19]. Soft metrology is defined as "*measurement techniques and models which enable the objective quantification of properties which are determined by human perception. The human response may be in any of the five senses: sight, smell, sound, taste and touch*". In the NPL report he highlights that Soft metrology can be a key factor in industrial applications. As well also the European community [20] [21] and CIE recognized [2] soft metrology as a key for competitiveness.

Samples

106 untrained observers evaluated six sets of three several achromatic gonio-apparent samples, in this paper we present only the results of the set Ia (Figure 1) composed for the perceived brightness and sparkle under two different light sources (LED and compact fluorescent lamp) with the same Correlated Colour Temperature (CCT), at fixed illuminance on the sample surface (about 600 lx) and for 4 different view angles, three of which defined in standards for multiangles measuring devices.

Every subject provided a ranking of the two perceived attributes for each group of materials for every direction of view. The groups were arranged in order to test the influences on the appearance of different material characteristics, see Table 1.

As appearance depends on a very large number of different factors [1] [2], we decide to test only few sample characteristics (table 1, "characteristic under test") and for two simple and easily understandable descriptors as brightness and sparkle.

Table 1 describes the samples characteristics.

Figure 1 shows the tested group.

Table 1: Tested samples, Material characteristics

SET	*Material Characteristic*
Ia	3 samples with natural mica particles with growing particle size 1A: 10-60 μm; 2A: <15 μm; 3A: 5-25 μm

Figure 1 Samples of set Ia on the left at 0° observation, on the right at 20° observation

Observers have to arrange each group of three samples in order from the brightest to the less bright, and from the higher sparkling, to the lower sparkling. In order to avoid influences on the arranged ranking, samples were identified just by symbols, as well the subjects randomly arranged first by brightness or by sparkling. All observers received the same written information about the test and the task (ranking by sparkle and by brightness).

The observers were free to spend as much time as they need to define the subjective ranking, as well to move samples to compare the perception. After arranging the samples each observer had to fill a form stating the perceived ranking using the symbols to identify samples, adding an equal sign (=) in case of equivalence between the perceived quality.

Observation boxes

Two identical observation boxes have been built in order to realize easy transportable systems to reach a larger number of subjects.

The boxes are shown in Figure 2.

The lighting source was put outside the box, while the samples exposed on a plain at 45°.

A medium grey diffuse fabric covered the inner of the boxes, as well the exhibition plane of the samples and the upper part of the samples: observers view the samples with the same mid grey background all around.

Figure 2 Observation box with samples on the exhibition plane left, with the observation shield right.

A shield with three fixed slot, corresponding to the observation angles of 0°, 20°, 30°, closed the box, and force the observer viewing direction. The largest slot in the bottom is for the observer to put the hands inside the box and arrange the sample on the plane (observers did not wear gloves, to help in source colour evaluation and colour constancy). The fourth viewing condition was with the shield open: the subjects were standing observing the samples, this last condition is most similar to real world behavior. Table 2 shows the different viewing conditions.

Table 2: Tested viewing conditions

Viewing condition	Angle of incidence	Angle of view (from the normal)
45/0	45°	0°
45/20	45°	20°
45/30	45°	30°
45/open	45°	Free

Lighting Test conditions

Two different CCT were tested: Cold White (CW) and Warm White (WW) sources. For each CCT two different sources were tested: a compact fluorescent lamp and a LED lamp.

Usually lighting engineering identifies source spectral characteristics by CCT and the Generl Colour Rendering Index (R_a). Acronym WW identifies sources with CCT lower than 3000 K, while CW sources with CCT higher than 4000 K.

R_a is a number related to the perceived colour difference of 15 different coloured samples, between the source and a reference source [22]: 100 means no difference in the perceived colours. Occasionally the perceived colours under LED can be substantially different from those under a fluorescent lamp, even if the sources have the same CCT and R_a.

The characteristics of tested sources are shown in Table 3 All measured values are acquired inside the box and refer to the tested condition. The values of R_i (special colour rendering index of 15 samples) are calculated values from the measured source spectrum. The mean illuminance on the sample plane was about 600 lx for all sources. The spatial distribution inside the boxes of the illuminance, as well as the emitted spectrum, has been measured, for example Figure 2 shows the illuminance distribution for CW sources.

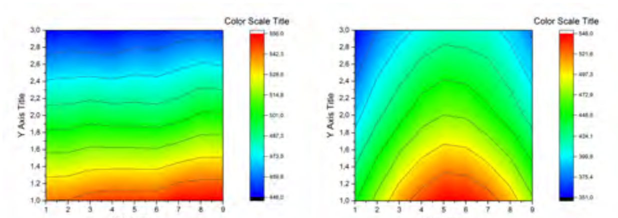

Figure 3 Illuminance distribution on the exhibition plane of CW sources, Compact fluorescent lamp left, LED right. The samples were arranged on a line in the green part

Table 3: Lighting source characteristic

Lighting characteristic		Warm White Sources		Cool White Sources	
		WW-LED	W-Fluorescent Lamp	CW-LED	C-Fluorescent Lamp
CCT [K]	Declared	2700	3200	4000	4200
	Measured	2765	3104	3990	3875
R_a	Declared	80	-	80	-
	Measured	83	86	85	87
R1	Light greyish red	82	94	83	92
R2	Dark greyish yellow	90	97	90	98
R3	Strong yellow green	96	57	93	58
R4	Moderate yellowish green	81	88	82	90
R5	Light bluish green	81	94	83	96
R6	Light blue	87	89	85	88
R7	Light violet	85	90	89	92
R8	Light reddish purple	65	76	72	86
R9	Strong red	22	22	29	45
R10	Strong yellow	77	62	75	64
R11	Strong green	78	84	80	86
R12	Strong blue	70	64	61	70
R13	Human complexion	83	91	85	91
R14	Leaf green	98	70	96	71
R15	Japanese skin	77	94	80	91

Data analysis

Samples characterization

Samples have been characterized inside the JRP xD-reflect consortium by the National Metrological Institute of Germany, Physikalisch-Technische Bundesanstalt (PTB), using a dedicated goniometer for spectral BRDF measurements, and portable multi-angle instrument Byk-Mac for sparkle and multi-angle color Byk-Mac. It is to note that the sparkle measurements are made with the Byk-Mac internal lamp, so are dependent from the instrument spectral lighting set-up.

The calculated and measured values (Y, L^*, measured Luminance in the observation box and sparkle) of samples are compared with the subjective responses, to reduce the amount of data, only the results of samples based in natural mica particles and Aluminium with silica layer (set Ia, Id and Sa in Table 2) are presented here. The goal is to verify the influences of viewing and illuminating condition vs materials characteristics, as well to verify the uniformity of measured/calculated values with perceived values.

It is to note that only instruments equipped with CCD or CMOS camera (Image Luminance Measuring Device ILMD) are able to discriminate luminance from sparkle, usual luminancemeter based on silicon photocell evaluates the reflected radiation without discriminate the two different behaviors. On the contrary, observers are able to discriminate very well luminance from sparkle. Table 4 shows the measured and calculated values for CW lamps, while Table 5 for WW lamps.

Table 4: measured and calculated values for Cool White (CW) sources

Set	Sample	Measured values 45/0						
		Y		L^*		Luminance [cdm^{-2}]		Sparkle
		LCW	FCW	LCW	FCW	LCW	FCW	intensity
Ia	1A	2,28E+01	2,29E+01	5,49E+01	5,50E+01	24,08 ± 2,32	84,55 ± 11,69	10,23
	2A	3,57E+01	3,58E+01	6,63E+01	6,64E+01	30,02 ± 3,07	75,09 ± 9,08	2,15
	3A	6,21E+01	6,17E+01	8,30E+01	8,28E+01	33,25 ± 2,65	73,59 ± 6,35	3,80

Table 5: measured and calculated values for Warm White (WW) sources

Set	Sample	Measured values 45/0				
		Y		L*		Sparkle intensity
		LWW	FWW	LWW	FWW	
Ia	1A	22,5649405	22,8100801	54,6213562	54,8761729	10,23
	2A	35,3402151	35,6705084	66,0126891	66,2673969	2,15
	3A	64,6679138	62,543775	84,3123195	83,2017544	3,8

Subjects data analysis

Observers had 1) to provide a ranking in the perceived properties of brightness and sparkle, 2) to judge two materials with equally perceived properties. The ranking was provided using only symbols and not letters or number in order to avoid any external hidden influences (Figure 1).

Each subjects evaluated all samples, in different order, under the two different lighting sources, for all the viewing conditions (Table 2).

The subjective responses have been analyzed considering the ranking and the equivalence as stated by all the observers. Table 6 shows the subjective ranking with the higher percentage of observer's judgments, for viewing condition 45/0. This condition is easily comparable with the measurements results: green colour highlights when the evaluations is correctly correlated with the measured quantity.

Table 6: Subjective ranking

Set	Ranking from higher to lower by perceived values 45/0							
	Brightness				Sparkle			
	LCW	FCW	LWW	FWW	LCW	FCW	LWW	FWW
Ia	2A 3A 1A	1A 3A 2A	2A 3A 1A	1A 3A 2A	1A 3A 2A	1A 3A 2A	1A 3A 2A	1A 3A 2A

The next figures show the subjective rankings for sparkle and brightness as well the occurrence of equivalences for samples based on natural mica particles belonging to set Ia.

Larger dispersions in observer evaluations are associated to a large number of equivalence occurrence in the judgments of visual attributes, comparing Figure 4 and *Figure 5*. Small ranking dispersions are associated with small occurrence of equivalence between judgments of different samples and are linked to sample characteristics and viewing conditions.

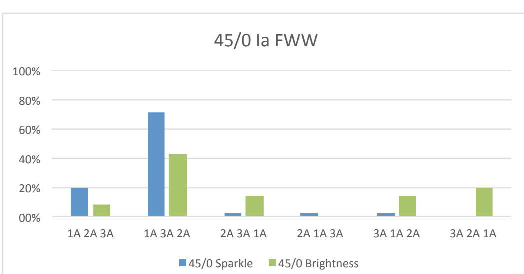

Figure 4: Brightness and sparkle ranking for 45/0 with Fluorescent WW source.

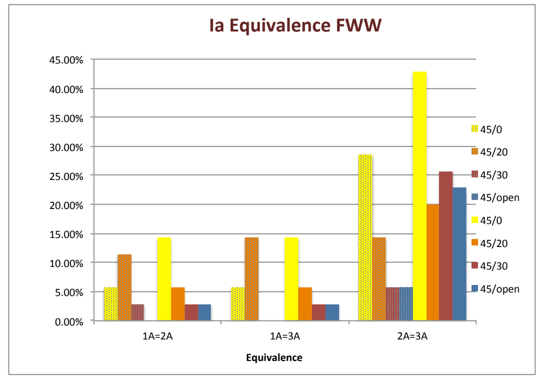

Figure 5: Brightness and sparkle equivalence occurrence (in solid equivalence in sparkle, in dot equivalence in brightness) with Fluorescent WW source and for all observation positions.

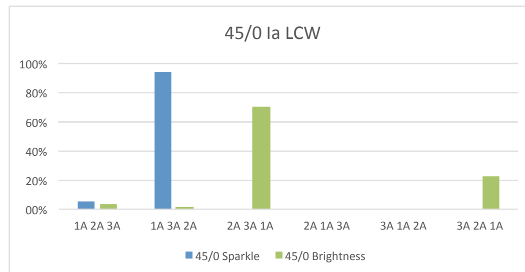

Figure 6: Brightness and sparkle ranking for 45/0 with LED CW source.

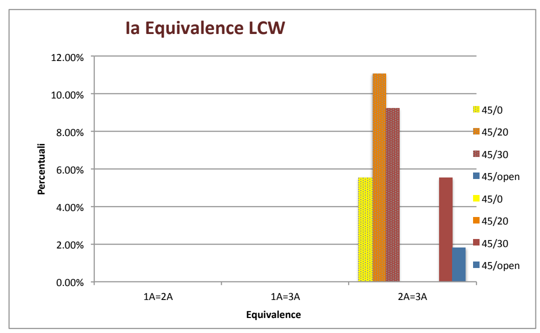

Figure 7: Brightness and sparkle equivalence occurrence (in solid equivalence in sparkle, in dot equivalence in brightness) with LED CW source for all observation positions.

The sparkle ranking is directly related to the particle characteristics: samples with higher sparkle have larger distribution of the mica particles size, i.e. sample 1A has the larger particle size distribution (10-60 μm).

Condition 45/open allows a more clear distinction between the two perceived quantities sparkle and brightness, independently from the lighting source, Figure 8.

LED sources allow a clear discrimination of sparkle from the brightness, independently from the observation condition. The discrimination is proved by two different rankings for the two characteristics and by a scarce occurrence of equivalence.

With fluorescent sources, the ranking does not highlight a difference in the two attributes and the occurrence of equivalence in judgment of sparkle and brightness, especially between sample

2A and 3A (2A particle size distribution is a large subset of 3A distribution), is large.

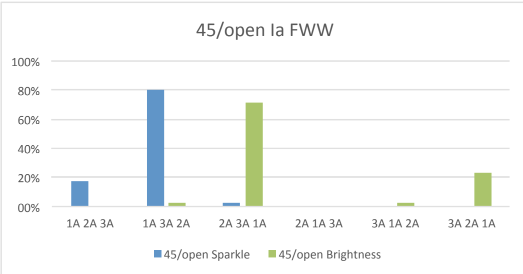

Figure 8: Brightness and sparkle ranking for 45/open with Fluorescent WW source.

Figure 8 and Figure 9show the occurrence of equivalence in set Ia for Fluorescent and LED (CW): the different behavior of the samples with LED lighting is clear.

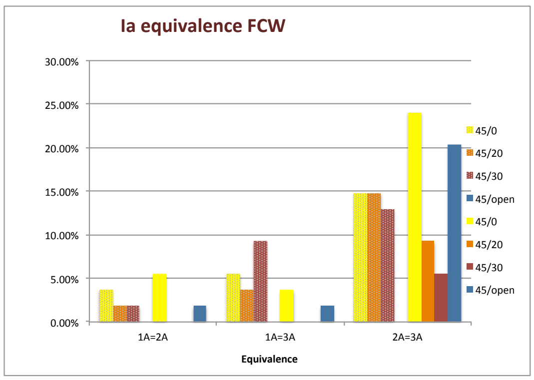

Figure 9: Brightness and sparkle equivalence occurrence (in solid equivalence in sparkle, in dot equivalence in brightness) with Fluorescent Cool sources for all observation positions.

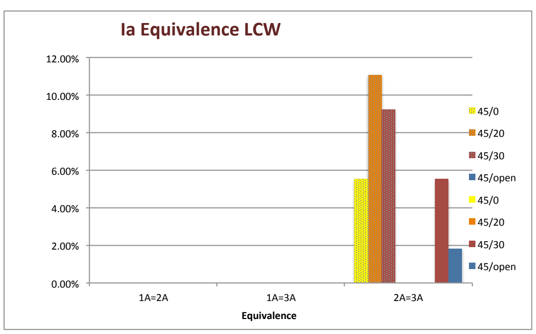

Figure 10: Brightness and sparkle equivalence occurrence (in solid equivalence in sparkle, in dot equivalence in brightness) with LED Cool sources for all observation positions.

Conclusions

Data analysis highlights a lack in the uniformity between measured values (Y, L^* and Luminance) and perceived quantity for brightness when goniochromatic materials are involved and a satisfactory uniformity for sparkle is acheived.

The higher uniformity between measured and perceived values of sparkle is basically related to the measurement device architecture: Sparkle measurement devices are based on CCD camera eventually equipped with optical systems. The adopted sparkle measurement algorithm is able to differentiate the reflected light by the mass sample from the sparkling which is associated to a fraction of the reflected light with intensity higher than a threshold (defined by the manufacturer). Luminancemeter and gonio-radiometer based on silicon photodetectors are not able to differentiate the reflection behavior and evaluate in full the reflected light. Each pixel of the device can be associated to an area of emission (this is related to the sparkle area measurement). This is a particularly interesting feature common to all devices equipped with CCD [23].

Fluorescent sources (CW and WW) are associated to a higher occurrence of equivalence in judgments, LED sources, especially the Cool one, have a lower rate of equivalence occurrence. Unfortunately LED sources are associated to higher discrepancies between objective measurement and perceived quality, especially when colour, brightness and glare are involved, but CIE is aware of the problem and new calculation methods, as well new LED sources are on the way [16], [24].

It is also clear a strong dependency between ranking and dispersion with viewing condition. Measurement conditions are not well representative of natural behavior, that in this experiment was represented by the condition 45/open. Specific viewing condition are related to higher dispersion, as well condition 45/open is always associated, for all samples and sources, to a lower judgments dispersion and equivalence occurrence.

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- To provide a deeper description of samples characteristics, authors need Merck authorization.

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