Graininess appearance of goniochromatic samples in lighting cabinets

https://doi.org/10.2352/ISSN.2470-1173.2017.8.MAAP-282

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P. Iacomussi, M. Radis, G. Rossi; INRIM; Torino, Italy

Abstract

In 2013 the European Metrology Research Program (EMRP) funded a 36 months research project, "Multidimensional Reflectometry for Industry, xD-Reflect", to investigate the macroscopic optical properties related to visual appearance of modern surfaces. During the three years duration of the project, over in August 2016, several visual experiments have been performed to investigate appearance of materials with goniochromatic and sparkling effects. Metal-flakes produce shiny effects whose definitions, quantities and metrological characterizations are still under development. This paper relates to the measurement and visual estimation of graininess and brightness perceived of metal flakes achromatic pigments materials. The subjective ranking on graininess and brightness of three different sample sets different for particles shape (silver dollar and corn-flakes) and dimension, were compared under similar viewing conditions on two commercial lighting booths, one based on LED lighting and one on fluorescent light, both reproducing CIE D65 illuminating conditions. The subjective rankings were compared with the graininess measured with a Byk-Mac instrument and the luminance measured with a luminancemeter in the experimental conditions inside both lighting booths. The performances of the two lighting cabinets and of the two different flake shapes were also compared. The results are useful both for shops lighting arrangements and industrial panelist investigations.

Introduction

Sparkling is an interesting property of metallic pigments: the first application arrived for automotive paint in 1935 with metal flake pigment made by Du Pont, the general market introduction dates back to 1950 [1]. Since then pigments and materials with special metal flakes able to realize new goniochromatic and shining effects were widely introduced on market and their application was not limited to car manufacturers: cosmetics, packaging, consumer electronics, no field is excluded because all fields needs to attract customers. Actually the visual perception and appearance of an object is considered a key parameter in customer satisfaction and its decision of buying: products appeal to customers according to their appearance. Appearance is "*the visual sensation through which an object is perceived to have attributes as size, shape, colour, texture, gloss, transparency, opacity etc.*" as defined by CIE (Commission International Eclairage) [2][3]. CIE defines Total Appearance [3] as the perception resulting from the combination of colorimetric (hue, saturation, brightness) and geometric (gloss, sparkle, texture, shape,…) material properties considering environmental conditions (attributes like illuminance, source spectrum, background,…) and observer behavior (visual adaptation, condition of view, expectations,…). It is quite obvious the difficulty of having a mathematical model describing Total Appearance. The ability of measuring and reproducing material appearance, with the assurance of metrology principles (measurand definition, reproducibility, accuracy), affect obviously the industrial competitiveness 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] in which these subjective experiments have been performed.

The modern materials, on which the xD-Reflect project is based, have sophisticate visual effects that stress the applicability of measurement methods and quantities definition. New lighting technologies such as LED sources are known for making more difficult predicting glare, color perception, color difference evaluation and material appearance in general, even in the case of reference materials.

To propose a model able to predict material total appearance is out of the scope of the xD-Reflect project and of this research. Total appearance prediction is very complex exercise and some experts advance doubts that it could be even possible to achieve [6] because its clear multidimensionality is related to several factors not easily assessable.

In order to be more effective and produce appropriate results Eugène suggests [2] to quantify the appearance of a product for defined applications and product characteristics.

The appearance experiments performed by INRIM in the xD-Reflect project refer to materials with metal flake pigments with goniochromatic, sparkling and metallic effects to improve knowledge about quantities definition and measurement methods involved in Appearance evaluations. INRIM investigated how material properties affects appearance evaluation for given lighting and viewing conditions considering different lighting source spectral distributions including LED, comparing measured quantities with the perceived attributes. Current measurements methods and quantity definitions related to appearance have been both developed for reference materials (ceramic tiles for color and dark glass for gloss) and for reference conditions. The most known appearance measurable quantities are those related to color and glossiness attributes: Colorimetric Coordinates, like CIE L*a*b* (L*C*h*), and Gloss, that is measured in GU (Gloss Unit) i.e. the ratio of specular reflection of the sample to a given reference material in given geometrical conditions. New materials with new perceived attributes need robust quantities definitions and measurement methods: sparkling effects are really customers attractive, but the measured quantities (Sparkle and Graininess) are relatively new: their definitions, measurement methods and consistency with the perceived attributes need to be tested and are object of this study.

This research states the brightness and sparkling perception considering the influence of shapes and size distribution of metal flakes pigments, comparing qualitative assessments and measured values for given viewing conditions with LED and Fluorescent sources of the same CCT (Correlated Colour Temperature) using two commercial lighting booths.

The study of visual attributes perception and prediction under LED and Fluorescent lighting sources, is a key action in order to provide effective results based on actual condition of evaluation as suggested by Eugène [2]: the use of LED as lighting sources is meant to grow because key actions on reducing electrical consumption by 2020 and ban of incandescent lighting source. More and more stores are renovating their lighting systems counting on customers attraction based also on sustainability of a renovated LED lighting system.

Manufacturers and industries use commercial lighting booth for panelist description of product appearance: commercial lighting booths are equally based on LED and Fluorescent sources, the most common produce a diffusing light distribution usually able to reproduce CIE Standard Illuminant of defined CCT. Only one commercial lighting booth is available for sparkle and graininess evaluation.

Perceived vs measured quantities

Metal flakes pigments produce shining effects related to the properties of the metallic flakes dispersed in the medium.

The relevant quantities of interest, from the point of view of the measurement [10] and perception [9], need to be identified with different descriptors. In this paper we use *Sparkle* and *Graininess* when referring to measured quantities of shining, while *sparkling* to perceived quality of shining. Unfortunately for *graininess* is not possible to use a different word for describing also the qualitative aspect, but the semantic significance is according to the sentence. Table 1 summarized the nomenclature used in the paper, including definition of ASTM[10].

Samples under test

Three different samples sets were used in the subjective experiment to test materials characteristics as particles shape, silver dollar and corn flakes, particles size, all at the same dark pigment concentration.

Only one commercial instrument able to measure sparkle and graininess is available on the market. The instrument was developed by car painting manufactures during an Eureka project [11] and unfortunately no deep metrological characterization has been made on the instruments that acts as a black box. A deeper knowledge on performances is needed for data analysis especially regarding uncertainty, spectral sensitivity and reliability.

The main characteristics (i.e. particles shape and dimension), and measured values of sparkle intensity (45° of incidence and 0° observation) and graininess of sample sets are shown in Table 2.

Table 1: Nomenclature

Word	Significance	ASTM Definition
Sparkle	the quantity measuring the *shining* under directional lighting conditions, is measured by commercial instrument as sparkle intensity, sparkle area and sparkle index for three different lighting directions (15°, 45°, 75°) and one observation (0°)	the aspect of the appearance of a material that seems to emit or reveal tiny bright points of light that are strikingly brighter than their immediate surround and are made more apparent when a minimum of one contributors (observer, specimen, light source) is moved
Graininess	the quantity measuring the *shining* under diffuse lighting conditions, it is measured using diffusing light provided by an integrating sphere	the perceived contrast of the light/dark irregular pattern exhibited by gonioapparent coatings when viewed under diffuse illumination

Table 2: samples sets characteristics

Set	No. of samples and metal flake shape	Dimension D50 particles	Measured Quantities Sparkle Intensity (15/0) / Graininess
Set A	5 samples corn-flakes shapes	1A: 10 μm 2A:14 μm 3A: 26 μm 4A: 35 μm 5A: 21 μm	2,74 / 3,09 3,74 / 3,71 6,6 / 4,52 8,35 / 5,47 4,67 / 4,44
Set B	5 samples silver dollar shapes	1B: 15 μm 2B: 9 μm 3B: 25 μm 4B: 34 μm 5B: 17 μm	8,23 / 3,8 2,88 / 2,89 18,39 / 5,77 18,17 / 7,17 11,65 / 4,17
Set 3	2 samples silver dollar corn flakes shapes	4A: 35 μm 4B: 34 μm	8,35 / 5,47 18,17 / 7,17

The measured sparkle intensity and graininess values define a ranking from low to high:

- for set A (similar for sparkle and graininess) 1A, 2A, 5A, 3A, 4A this ranking is in agreement with particles dimensions;
- for set B, some discrepancies arrive considering graininess values and sparkle intensity, 2B, 1B, 5B, 4B, 3B for sparkle, and 2B, 1B, 5B, 3B, 4B for graininess,

this last sequence is in accordance with particles dimensions too.

Because the lighting distribution in the lighting booths is mostly uniform (i.e. no direct illumination is provided inside the booths) the reference measured quantity used in comparison of subjective qualitative evaluation is the graininess value.

Subjective investigations

28 untrained subjects aged 21-30 equally distributed between males and females, attended the experiments under constant adaptation condition: the experiment was conducted in an obscured lab under reference conditions.

Lighting Booths

Two different commercial lighting booths, one LED and one Fluorescent lamp equipped, both reproducing CIE D65 illuminant in diffuse lighting condition were used. It is to note that these lighting booths are usually used for color evaluation but are also the most commercially distributed. The same company that developed the commercial instrument for Sparkle measurement, developed also its own lighting booth for sparkling visual evaluation. This booth provides diffuse light (using a fluorescent lamp) for graininess evaluation and directional light (using LED) for sparkle evaluation.

Table 3 shows, for main lighting parameters, mean values and their standard deviation calculated on the area used in the experiment for samples evaluation and not over the whole sample plane of the lighting booth. The measurement uncertainty on illuminance values is 6%, while on CCT values is 30K.

Table 3: Lighting booth characterisation

Quantity	LED Lighting Booth	Fluorescent Lighting Booth
Max illuminance [lx]	1594	2207
Mean illuminance over the sample area [lx]	1566 ± 22	2086 ± 85
Uniformity (Mean illuminance/Max illuminance)	0,98	0,94
Mean Correlate Color Temperature over the sample area (CCT) [K]	6443 ± 16	6710 ± 11
Ra	94,65 ± 0,07	95,53 ± 0,17

The difference in illuminance between the two lighting booths is unavoidable because only the intensity emission of LED cabinet can be controlled and for the experiment was set to the maximum values.

Ra is a parameter used to assess the difference in color rendering capabilities of a source with reference to a reference source (in this case D65), closer to 100 the value, lower is the difference in color rendering capabilities on 14 reference colored samples of the source. The measured values highlight that some differences in the rendering capabilities with reference to D65 arrives for both lighting booths. The differences between LED and Fluorescent Ra values are not significant because is well known that the available color rendering metric do not easily apply to LED [12].

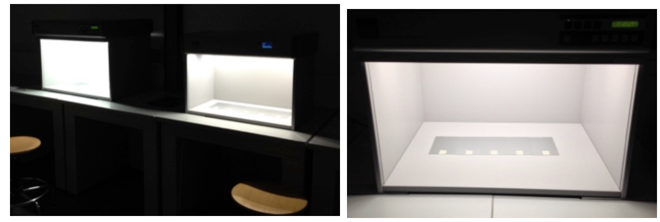

Figure 1: left: the two lighting booths used during the experiment, right: the fluorescent lighting booth

Figure 2: left: the sample set A under the fluorescent lighting booth; right: the sample set B under the LED lighting booth [Ed: the lines are due to effects of pulse modulation control on LED]

Figure 3 shows the spectral distribution of the two lighting cabinet. The difference in the spectrum between LED and Fluorescent lamp is mostly in the blue region and produce the measured differences in CCT as well Ra values.

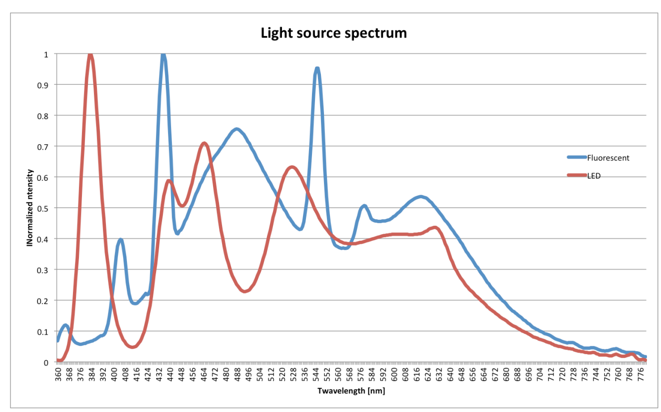

Figure 3: Mean spectral distribution of LED and Fluorescent lighting booths measured on the sample area

Data analysis

Each subject received written instruction explaining the assigned task: for every sample set and for every lighting booth the assignment was to put the samples, identified by symbols, in a ranking of perceived graininess and perceived brightness, reporting the ranking list of symbols on a form. The order of presentation of tasks was randomly arranged. Subjects sat on an adjustable stool to assure that the angle of observation was kept constant for all. The samples were aligned in the center of the sample plane area and subjects kept them on the same line during the whole duration of the experiment.

Two additional questions in the subject's response form, asked to identify in which lighting booth was easier to perform the assigned task of perceptive evaluation of graininess and brightness. In total each subject performed 12+2 evaluations: 3 (sample sets) x 2 (perceived quantities) x2 (lighting conditions) + 2 (easier evaluation of perceived quantity).

The results were statically analyzed comparing the subjective ranking with the respective measured quantity of Graininess and Lightness and the performances achieved under the two different lighting sources.

For graininess the perceived ranking is coherent with the measured quantity ranking (i.e. Graininess value) and particle dimensions as stated above. But under fluorescent light the subjective evaluations are more difficult to perform.

Indeed comparing subjective performances under LED and Fluorescent light, the advantages of using a LED equipped lighting cabinet are clear as shown in the following figures. In Figures 4 and 5 the graininess evaluation of Set A under fluorescent and LED lighting is shown.

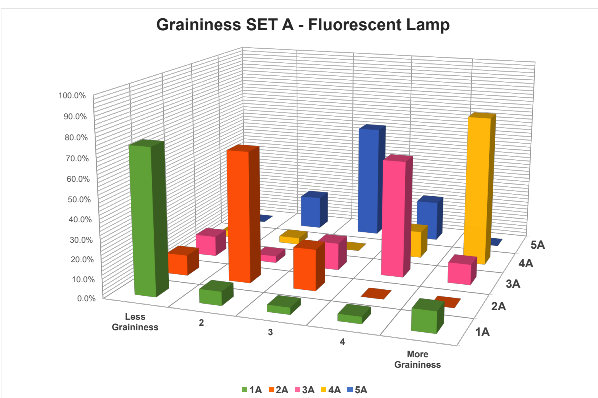

Figure 4: Data dispersion for sample set A in graininess evaluation under Fluorescent lighting booth

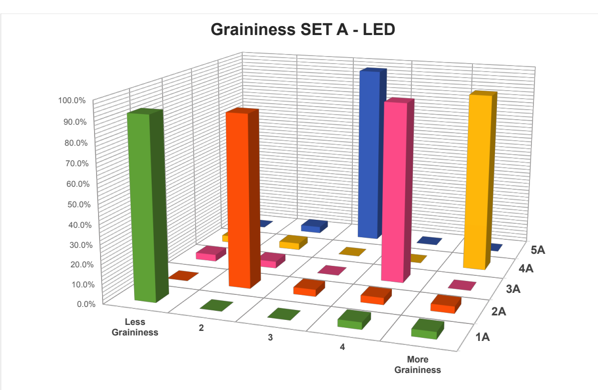

Figure 5: Data dispersion for sample set A in graininess evaluation under LED lighting booth

Analyzing the judgments distribution a different behavior is clearly related to the lighting sources: LED cabinet provides a lower data dispersion. The LED source helped subject in evaluating the differences in perceived graininess also in the case of samples with very similar measured values, i.e. samples pair 1A 2A and 3A 5A. While under fluorescent light a larger dispersion of data arrives.

These results are also confirmed for Set B (silver dollar).

From the comparison of perceived graininess of the sample Set 3, i.e. test metal flakes shapes influences, silver dollar and corn flakes, it is clear that with the same particle dimension distribution, the silver dollar is perceived as more sparkling and this is a confirmation of previously research data [9].

Regarding the judgments about the intrinsic difficulty of subjective evaluation in the two different lighting booths, the advantage of LED lighting booth is clear also from the results of the dedicated question (Figure 6) and from the data dispersion analysis.

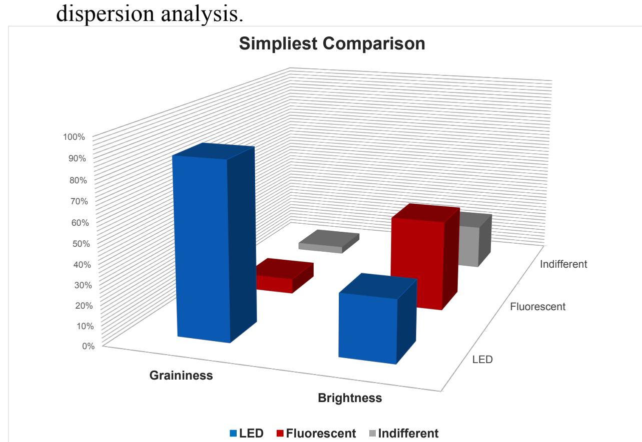

Figure 6: Evaluation about the difficulties experienced in doing the experiments under the different lighting sources observation box.

Conclusions

This paper presents the results of subjective tests on graininess perception of achromatic materials with metal flakes pigments of different shapes and dimensions, performed during the European Joint Research project xD-Reflect. The tests were performed using two commercial lighting booths with LED and Fluorescent sources, both reproducing CIE D65 illuminant. All results highlight that the two lighting booths provide different performances: subjective evaluation of graininess benefit of LED lighting. Subjects clearly stated that the graininess evaluation was easier under the LED than under the Fluorescent lighting booth, indeed the result is confirmed by a shorter execution time and a smaller dispersion of data in the subjective ranking. While considering the brightness perception it is not possible to define a clear advantage in using one of the two lighting sources.

The results of both samples Set A and Set B confirm that larger flakes caused higher brilliance and sparkle, under both lighting sources and the subjective ranking is consistent with the measured one with a higher occurrence of equivalences and dispersion in subjective evaluations.

The results of sample Set 3, same particles dimensions distribution but different shapes (silver dollar vs corn-flakes) confirmed, for both lighting sources, that sparkling/graininess performances depends on the shapes of flakes: round smooth flakes, like silver dollar, produce higher sparkling graininess effect. Corn flakes shapes, with their sharp profile produce a larger spatial scattering of the reflected light that is more identified with brightness than graininess/sparkling.

The two different performances of the lighting booths are coherent with those of a previous research on sparkling evaluation under LED and Fluorescent lighting made by the authors obviously considering directional light [13].

In both researches, performances of LED and Fluorescent lighting were compared for the evaluation of sparkle, graininess and brightness of goniochromatic materials with metal flakes pigments.

Both researches highlight that spectral investigations on Sparkle and Graininess are needed: subjective rankings are consistent with measured properties, but an improvement in the measurement methods for Sparkle and Graininess is necessary because subjective experiments highlights a different behavior related to the lighting source. Currently Sparkle and Graininess are defined, and measured, as ratio of the flux reflected by the sparkling flakes and the surroundings. The different performances of lighting source in the subjective experiments could be related to the different spectral distribution of the emitted light: LED has a larger emission in the blue region than the Fluorescent lam (see Figure 3) besides metal flakes in the studied samples have high reflectance in the blue region: this could be an explanation of the different subjective performances. The subjective results clearly highlight that radiometric investigations are needed to improve definition and measurement methods for Sparkle and Graininess evaluation. These investigations could be considered as future goal for a new research project starting from the results achieved with Multidimensional Reflectometry for Industries xD-Reflect.

Acknowledgement

Authors are grateful to:

- Merck KGAa for providing the samples;
- Minolta for providing a brand new LED equipped Observation booth;
- PTB Colleagues for providing samples and BRDF and sparkle/graininess measured data;

This work is part of the European research project "Multidimensional Reflectometry for Industry" EMRP Project IND52 xD-Reflect. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

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Author Biography

Paola Iacomussi received her BS in Physics from the University of Torino. Since then she has worked in Research firstly in the automotive industry and (1995) at INRIM (formerly IEN), the Italian National Metrology Institute, "Nanoscience and Material Dept.". She works on optical materials and source characterization and perception, including works of arts. She is also Adjunct professor at the University of Torino.

Michela Radis received her BS in Science and Technology for Cultural Heritage in 2011 and she is PhD Student at Politecnico di Torino with a research on material optical attributes related to visual perception.

Giuseppe Rossi is senior researcher at INRIM (formerly IEN), the Italian National Metrology Institute,"Stalt" Dept He works on lighting engineering, material and source characterization. He is strongly involved in the European and Italian Standardization bodies (CEN and UNI). He is also Adjunct professor at the University of Tori