Minimal Number of Measurements for Color, Sparkle and Graininess Characterization in Gonio-apparent Panels

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Abstract:	Materials with new visual appearances have emerged over the last few years. In the automotive industry in particular, there is a growing interest in materials with new effect finishes, such as metallic, pearlescent, sparkle and graininess effects. Typically for solid colors the mean of the three measurements with repetitions it is enough for obtaining a representative measurement of the color characterization. But gonio-apparent samples are colors not homogeneous and there are not studies that recommend the minimal number of repetitions for color, sparkle and graininess characterization in this type of panels. We suppose that the color panels incorporating special-effect pigments in their color recipes will require a higher minimum number of measurements than solid color panels. Therefore the purpose of this study is to confirm this by using a multi-angle spectrophotometer BYK-mac, given that it is currently the only commercial device that can measure color, sparkle and graininess values simultaneously. In addition, this paper shows a possible methodology for assessing the minimum number of measurements when characterising gonio-apparent materials using a specific instrument. Thus, we studied the minimum number of measurements needed to characterize the color, sparkle and graininess of three types of samples with solid, metallic and

	pearlescent coatings, respectively. Twenty measurements were made, at twenty random positions (different target areas) of the ninety samples. The minimum number of measurements for all these variables was determined taking into account when the cumulative mean value became constant.

Minimal Number of Measurements for Color, Sparkle and Graininess Characterization in Gonio-apparent Panels

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Materials with new visual appearances have emerged over the last few years. In the automotive industry in particular, there is a growing interest in materials with new effect finishes, such as metallic, pearlescent, sparkle and graininess effects. Typically for solid colors the mean of the three measurements with repetitions it is enough for obtaining a representative measurement of the color characterization. But gonio-apparent samples are colors not homogeneous and there are not studies that recommend the minimal number of repetitions for color, sparkle and graininess characterization in this type of panels. We suppose that the color panels incorporating special-effect pigments in their color recipes will require a

higher minimum number of measurements than solid color panels. Therefore the purpose of this study is to confirm this by using a multi-angle spectrophotometer BYK-mac, given that it is currently the only commercial device that can measure color, sparkle and graininess values simultaneously. In addition, this paper shows a possible methodology for assessing the minimum number of measurements when characterising gonio-apparent materials using a specific instrument, able to be implemented in future instruments multiple appearance attributes (color, gloss, sparkle, etc.) for many coloration technologies. Thus, we studied the minimum number of measurements needed to characterize the color, sparkle and graininess of three types of samples with solid, metallic and pearlescent coatings, respectively. Twenty measurements were made, at twenty random positions (different target areas) of the ninety samples. The minimum number of measurements for all these variables was determined taking into account when the cumulative mean value became constant. So, it is clearly shown here, applying new statistical tools, that the metallic and pearlescent panels need more color measurements than solid ones, and in particular in the measurement geometries around the specular direction. And, about texture (sparkle and graininess), more measurements are necessary for graininess than sparkle, and more for metallic panels than pearlescent ones.

1.Introduction

Gonio-apparent panels refer to materials that present notable color changes under different viewing angles and lighting conditions. Panels with metallic finishes usually show a change in lightness, while those with interference finish effect also exhibit hue and chroma changes. Due to this, to characterize this type of panels it is important to measure the color at different measurement geometries[1-3]. Nowadays, there are several color-measuring instruments, known as multi-angle spectrophotometers or gonio-spectrophotometers, which have been designed to measure and characterize homogeneous colors in these types of panels. The measurement geometries of these devices usually agree with the requirements established in the ASTM, DIN and ISO standards[4-6] which refer to the characterization of gonio-color appearance. However there are other types of non-industrial devices or scientific prototypes providing a lot of extra measurement geometries[2].

Materials with new visual appearances have emerged over the last few years. In the automotive industry in particular, and also in cosmetics and plastics for consumer electronics, there is a growing interest in materials with new effect finishes. Their popularity is due to the fascinating interplay of colors and the effects produced by the various materials used in their layered structures[7-9]. Refractions and reflections of light at and within these layers cause light interferences that yields certain colors[10]. Thus, depending on the pigments, the panels can have an interference finish or sparkle and graininess effects when special-effect pigments are used. The sparkle effect (also known as sparkling effect, micro brilliance~~, or~~ glint or glitter) is generated by the reflectivity of the individual flakes that act like tiny mirrors and is observed under intense directional illumination. In contrast, and for the same panel, the viewing angle is not relevant when studying the graininess effect (also described as coarseness or salt and pepper appearance), which is observed under diffuse illumination. Both contribute in different ways to the visual texture over the panel. It should be pointed out when we say visual texture, it refers to the texture appearance due to the sparkle and graininess of the sample. In addition, because of the variable position of these pigments, the color and visual texture that is measured is not constant over the entire panel.

Panels with solid colors can be characterized with conventional color devices, such as those based on integrating spheres. Panels with metallic or interference finish effect must be characterized with multi-angle spectrophotometers, which are capable of characterizing homogeneous colors at different measurement geometries. However, these color devices calculate the color values by averaging the spectral reflection over the entire illuminated spot, which means that they are unable to extract the information about the reflection of the metallic or pearlescent flakes. Despite the fact that these types of devices can measure color at several geometries, they cannot measure the grade of sparkle or graininess of the panels with this procedure.

There is currently only one commercial device able to measure color and visual texture (sparkle and graininess) under different viewing angles and illumination conditions simultaneously – the BYK-mac multi-angle spectrophotometer[11]. This device measures the sparkle and graininess effects using a high resolution monochrome CCD camera that characterizes effect changes perceived under direct and diffuse lighting conditions[12, 13]. The used model in this work was the BYK-mac 23 mm.

Given that the orientation of special pigments is variable[14], for panels with a sparkle effect it is expected to obtain different sparkle and graininess values, and even different color values, at different measurement positions. There are studies based on standard institutions (CIE, ASTM, etc.) recommending a minimum number of measurements at different positions to characterize solid color samples, even with low graininess or sparkle.";. However, they do not provide recommendations on the minimum number of measurements needed to characterize colors with special-effect pigments, such as panels with sparkle or/and graininess effects.

Our expectation is that color panels incorporating special-effect pigments [9, 15] in their color recipes will require a higher minimum number of measurements than solid color panels for color, sparkle and graininess characterization, because color solid samples are homogeneous over the entire surface and special effects are variable. Consequently, the purpose of this study is to confirm this by using the multi-angle spectrophotometer BYK-mac. In addition, the study also focuses on analyzing whether there are differences in the minimum number of measurements needed to characterize three types of samples typically used in the automotive sector: solid, metallic and pearlescent. Color and visual texture at different measurement geometries were carried out for the characterization; the parameters studied were the colorimetric, sparkle and graininess values at six, three and one measurement geometries, respectively.

2.Materials and Methods

Measurement Device

The BYK-mac multi-angle spectrophotometer is capable of measuring reflectance at six geometries for color characterization, three geometries for sparkle and one geometry for graininess characterization, simultaneously. This device characterizes color by measuring the sample under different aspecular angles: -15º, 15º, 25º, 45º, 75º and 110º. Following CIE standards, these geometries are represented as 45ºx:-60º, 45ºx:-30º, 45ºx:-20º, 45ºx:0º, 45ºx:30º and 45ºx:65º, respectively (figure 1).

Similarly, this device characterizes sparkle, S_g, by measuring in a perpendicular direction to the sample and under an illumination angle of 15º, 45º and 75º. Following CIE standards, these geometries are represented as 15ºx:0º, 45ºx:0º and 75ºx:0º, respectively (figure 2). Graininess, G, is evaluated by measuring in a perpendicular direction to the sample and under diffused illumination (figure 2).

The sparkle and graininess measurements are determined by taking a picture with a monochrome CCD camera under direct and diffuse lighting conditions, respectively. The pictures are analyzed by means of image-analysis algorithms using the histogram of intensity levels as the basis for calculating sparkle and graininess parameters[11]. Although the algorithms used are not public, it is known that this device calculates the sparkle, S_g, by combination of two intermediated values of sparkle: area and intensity, S_a and S_i. The sparkle of area, S_a, is a measure indirectly related to the flake size but it does not means that sparkle of area measures the size of the individual effect pigments. The sparkle of intensity, S_i, is designed to take into account the intensity of the reflection. Accordingly to this, these three parameters were used in this study, i.e. S_g, S_i and S_a, taking into account the relative intensity (in digital counts) of the reflection. The graininess value is obtained directly from the histogram of intensity levels of the picture recorded under diffuse lighting conditions.

Sample Measurement

Thirty samples were chosen for each type of pigment or color recipe: thirty solid colour, thirty metallic and thirty pearlescent samples. The colors were selected to cover a large proportion of the color gamut, as it is shown in figure 3, where all measurement geometries are plotted together.

For solid colour samples (blue dots) some clusters can be observed. This can be simply explained by the fact that solid colour samples do not show a color shift when the measurement geometry changes. On the contrary, for metallic and pearlescent samples no clusters are shown because they exhibit changes in color with the measurement geometry.

Twenty measurements at random positions were made for each sample, from which the cumulative mean value for colorimetric values at six measurement geometries (L*a*b* at -15º, 15º, 25º, 45º, 75º and 110º), sparkle values at three measurement geometries (S_g S_i and S_a at 15º, 45º and 75º) and graininess values at one measurement geometry (G) were calculated for all measurement geometries and plotted. As an example, Figure 4 provides three of the twenty-eight cumulative mean values (L* at -15º, S_i at 45º and G) for a solid, a metallic and a pearlescent sample.

The minimum number of measurements was selected as that obtained when the corresponding cumulative mean value reached the horizontal asymptote, i.e. was kept constant. The following statistical formula[16] was used to objectively establishing a method to determine when the minimum number of measurements became constant:

$$n = \frac{N\sigma^2 Z^2}{(N-1)e^2 + \sigma^2 Z^2} \qquad (1)$$

where N is the population size, σ is the standard deviation, Z is a value linked to the required confidence level (equivalent to 1.96 for a confidence interval of 95%) and e is the acceptable limit of sampling error which we assumed as 1 unit. The following equation was used to calculate the mean confidence interval in a small population or when sampling without replacement:

$$\bar{x} - Z\frac{\sigma}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}} = \mu = \bar{x} + Z\frac{\sigma}{\sqrt{n}}\sqrt{\frac{N-n}{N-1}} \qquad (2)$$

Following this procedure, we obtained the results for each type of pigment recipe with the minimum number of color measurements for individual samples and geometries.

The same results were computed for the minimum number of sparkle and graininess measurements. The values obtained for all samples are plotted with a vertical blue line in Figure 4. Equation 2 was applied for each individual sample and each geometry in order to determine the minimum number of measurements to characterize color and visual texture. In Figure 4, the results for some samples are plotted with a vertical blue line in the graphs.

Statistical Analysis

Data analysis was performed using SPSS software (version 21, SPSS, Chicago, IL, USA) for Windows. A α value of 0.01 was considered significant.

The main purpose of this study was to assess the dependency on the minimum number of measurements to characterize the color, sparkle and graininess with the type of panel color recipe and measurement geometry. With this in mind, samples were measured in all geometries, which means that they were related measurements. Therefore, multivariate analysis of variance (MANOVA)[16-18] was used to analyze the data. The SPSS statistical program was used for the computations. Some considerations have to be kept in mind to apply this analysis. As said before, the samples have been measured in all geometries, which means that they are related measurements. Thus, the geometry acts as a dependent variable and the type of pigment as an independent one. On the other hand, for applying the MANOVA analysis, it is necessary to fulfill some requirements (normal distribution and homogeneity of variance). However, in some geometries the data did not satisfy these requirements because some had a constant value. Due to this we represented the data using a box plot, which provided us with an overview of the quantitative data. Based on the results of these box plots, we were able to decide which data could be subjected to independent statistical analysis for individual geometries and which data did not require further analysis.

In a second step, an analysis of variance (ANOVA) was used to test for significant differences in the minimum number of measurements. The null hypothesis of this test is that the minimal number of measurements for solid samples is the same as that for metallic or pearlescent samples. When the ANOVA F-test was significant, post hoc analyses were carried out. The Kolmogorov-Smirnov test (K-S test) was used to test for normality of the data and the Bartlett test was used to check for homogeneity of the variance. When significant heterogeneity was found, data was transformed by $\sqrt{(x + 1)}$ or $\ln(x + 1)$. When transformations did not remove heterogeneity and/or the distribution did not follow a normal distribution, analyses were performed on the untransformed data with the F-test α-value set at 0.01. This can be done since ANOVA is robust enough to depart from this assumption, especially when the design is balanced and contains a large number of samples or treatments[18].

3.Results

Figures 5-7 illustrate the box plots of the results for the three studied variables: color, sparkle and graininess measurements. The bottom and top of the box are the first and third quartiles, and the black band inside corresponds to the median. The ends of the whiskers represent the minimum and maximum values of all data. Any data not included between the whiskers is plotted as an outlier with an asterisk. These results enable us to decide when a statistical study is necessary for each individual case and to recommend a minimum number of measurements for the characterization of color, sparkle and graininess parameters. In an ideal case it is expected to need only a single measurement for a characterization of color, sparkle and graininess. However, the special properties of the pigments will make this number to increase in some cases.

Color Measurements

Figure 5 illustrates the box plot of the minimum number of color measurements for the set of thirty samples with solid pigments, as well as those with metallic and pearlescent pigments. The results showed that a single measurement, and using a BYK-mac, was needed to determine the color in four geometries (25º, 45º, 75º and 110º from specular angle), regardless of the type of pigment recipe, given that the height of the box matched the width of the whiskers. It means that the upper and lower quartile were both one and they match with the box, i.e., they required just one measurement. In addition, the data was not analyzed by means of an ANOVA test because all values were constant.

On the other hand, in the two geometries closest to the specular angle (-15º and 15º), the boxes became higher and the whiskers became wider, meaning that a larger number of measurements were necessary to determine the color for all types of samples; For these geometries the boxes of pearlescent samples were higher than the boxes of metallic samples, and even higher than the boxes of solid ones. Therefore, it can be concluded that a greater number of measurements were needed to determine the color for metallic samples than for solid ones. An even greater number of measurements were necessary to determine the color for pearlescent samples. An analysis of variance was carried out in this case to study whether there were significant differences between the means. The results of the one-way ANOVA test with a factor type of pigment for the minimum number of color measurements are shown in Table 1.

As it can be seen, the p-value was greater than 0.01 for the two geometries closest to the specular angle (-15º and 15º), which means that there were no significant differences between the averages of the minimum number of color measurements. Therefore, these results indicated that two measurements were necessary for the color characterization using these geometries. Because the average results of measurement number always were decimal numbers, they were rounded up to the nearest whole number.

Sparkle Measurements

The same steps described in the previous section were used for sparkle measurements. Figure 6 shows the box plot of the minimum number of sparkle measurements for the same data.

In this case, a larger number of measurements were needed to determine the sparkle, given that the boxes became higher and the whiskers became wider in all geometries and for all types of pigment. Moreover, the results showed that the minimum number of measurements was always lower for the solid samples than for the metallic and pearlescent samples, which is consistent with the fact that solid samples do not exhibit sparkle effect. It was for this reason that the ANOVA test was only carried out with metallic and pearlescent data.

On the one hand, despite of fact that the solid samples do not have sparkle, sometimes the measured sparkle values are not exactly zero because of the measurement uncertainty. Not surprisingly, the first quartile and the median are both at zero for solid colors. We use the third quartile to indicate the minimal number of measurements for minimizing the uncertainty.

On the other hand, the results of the ANOVA test for the minimum number of sparkle measurements for metallic and pearlescent samples (Table 2) showed that there were no significant differences for sparkle characterization at 15º, 45º and 75º between the averages of the metallic and pearlescent samples as p-value > 0.01 were obtained in all cases. We could therefore conclude that four measurements were needed for sparkle characterization at 15º, five at 45º and four at 75º regardless of whether the samples were metallic or pearlescent.

Graininess Measurements

The same methodology was also used for graininess measurements. In this case, Figure 7 illustrates the box plot of the minimum number of graininess measurements for the same data and similar conclusions to those obtained for sparkle analysis could be drawn.

The results proved that the minimum number of measurements for the solid colour samples was always lower than for the metallic and pearlescent samples (three measurements). Consequently, the ANOVA test was only carried out with metallic and pearlescent sample data. The results are shown in Table 3.

As shown, there were statistically significant differences between the averages of the metallic and pearlescent samples in terms of graininess characterization, meaning that in this case nine or six measurements were needed, respectively (Figure 7).

4. Discussion and Conclusions

This paper shows a methodology for assessing the minimum number of measurements when characterising gonio-apparent materials using a specific instrument, particularly designed and built for offering some visual appearance attributes, as the current BYK-mac. But, this approach could be applied in future to new visual appearance instruments, even including gloss, goniofluorescence, translucency, etc., for many colorations industries (automotive, coatings, plastics, printing, cosmetics, textile, leather, etc.) using special-effect pigments.

Regarding the characterization of color, the results of this study showed that a single measurement was needed to determine the color in four angles (25º, 45º, 75º and 110º from specular angle), regardless the type of pigment recipe. In addition, two measurements were needed for the characterization of color in the two geometries closest to the specular angle (-15º and 15º), which is consistent with the fact that these geometries are very close to a specular angle and that this can greatly affect the results.

In terms of sparkle and graininess, the minimum number of measurements for the solid colour samples was always lower than for metallic and pearlescent samples, which is consistent with the fact that solid colour samples lack sparkle and graininess. Therefore, in this case only one measurement is necessary in order to assess the lack of sparkle or graininess.

However, for sparkle characterization the statistical study also showed that it was not necessary to make any distinction between metallic or pearlescent samples. In this case, four measurements were needed at 15º, five measurements at 45º and four measurements at 75º.

Finally, with regards to the characterization of graininess the conclusion was that there were significant differences between the means of metallic and pearlescent samples, meaning that nine or six measurements were needed in this case, respectively.

In conclusion, this study demonstrates that using a BYK-mac instrument, though applicable to new multi-angle spectrophotometers, more than one measurement is often necessary at each measurement geometry to properly account for color, sparkle and graininess effects in samples including special-effect pigments. This can have an impact in some industries, especially in the automotive sector, in which new effect finishes are commonly used.

Therefore, this study could be interesting to be applied again in other specific panel sets previously designed for evaluating the influence of the coating method application, size and shape of special-effect pigments, types of interference pigments and their concentrations in recipes, etc.

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5. References

1. Chorro, E., et al., *Colorimetric and spectral evaluation of the optical anisotropy of metallic and pearlescent samples.* J. Mod. Optic., 2009. **56**(13): p. 1457-1465.
2. Ferrero, A., et al., *Spectral BRDF-based determination of proper measurement geometries to characterize color shift of special effect coatings.* J. Opt. Soc. Am. A, 2013. **30**(2): p. 206-214.
3. Perales, E., et al., *Desafios na medição e caracterização do goniocromatismo.* Revista Química Têxtil, 2009. **96**: p. 39-48.
4. ASTM, *Standard Practice for Multiangle Color Measurement of Metal Flake Pigmented Materials*, 2012, ASTM International: West Conshohocken, PA.
5. ASTM, *Standard Practice for Multiangle Color Measurement of Interference Pigments*, 2012, ASTM International: West Conshohocken, PA.
6. Kirchner, E. and W. Cramer, *Making Sense of Measurement Geometries for Multi-angle Spectrophotometers.* Color Research and Application, 2012. **37**(3): p. 186-198.
7. Cramer, W.R. and P. Gabel, *Measuring special effects.* Paint & Coating Industry, 2001. **29**(9): p. 36-46.
8. Kirchner, E., et al., *Observation of visual texture of metallic and pearlescent materials.* Col. Res. Appl., 2007. **32**(4): p. 256-266.
9. Pfaff, G., *Special effect pigments : technical basics and applications.* 2008, Hannover: Vincentz Network. 218.

10. Douma, M. *Causes of Colours*. 2008 March 2010 [cited 2013; Available from: http://www.webexhibits.org/causesofcolor/15.html.
11. GmbH, B.-G. *Metallic color*. 2013 May, 2013 [cited 2013; Available from: http://www.byk.com/fileadmin/byk/support/instruments/technical_information/datasheets/English/Color/Metallic/Complete_Color_and_Effect_Measurement_of_Metallics_Multi-angle_color_and_Sparkle__Graininess_control_.pdf.
12. Dekker, N., et al., *Total appearance differences for metallic and pearlescent materials: Contributions from color and texture.* Color Research & Application, 2011. **36**(1): p. 4-14.
13. Kirchner, E., et al., *Observation of visual texture of metallic and pearlescent materials.* Color Research & Application, 2007. **32**(4): p. 256-266.
14. Kirchner, E. and J. Houweling, *Measuring flake orientation for metallic coatings.* Progress in Organic Coatings. **64**(2-3): p. 287-293.
15. Klein, G.A., *Industrial Color Physics.* Industrial Color Physics, 2010. **154**: p. 1-497.
16. Triola, F.M., *Estadística elemental.* 7 ed. 2000: Addison Wesley.
17. Prieto, B., et al., *Measuring the Color of Granite Rocks: A Proposed Procedure.* Color Research and Application, 2010. **35**(5): p. 368-375.
18. Underwood, A.J., *Experiments in ecology: their logical design and interpretation using analysis of variance*, ed. C.U. Press. 1996, Cambridge. 504.

Figure 1 Schematic representation of the illumination/measurement geometries used by the BYK-mac device for color characterization.

Figure 2 Schematic representation of the illumination/measurement geometries used with the BYK-mac device for sparkle and graininess characterization.

Figure 3. Sample selection represented in the diagram of the CIE L*a*b* space. All measurement geometries are plotted together.

Figure 4. Cumulative mean values for a solid, a metallic and a pearlescent sample (L* at -15º, S_i at 45º and G). Blue line is the proposed minimum number of measurements after applying statistical analysis.

Figure 5. Box plot of the minimum number of color measurements in samples with different types of panel color recipes for different measurement geometries.

Figure 6. Box plot of the minimum number of sparkle measurements in samples with different types of pigments for different measurement geometries.

Figure 7. Box plot of the minimum number of graininess measurements in samples with different types of pigments.

Table 1. Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: solid, metallic or pearlescent), for the minimum number of color measurement. df: degrees of freedom; F: F-test. Dash (–) indicates that there is no transformation. Superscript a indicates that the level of significance is $p < 0.01$.

Table 2. Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: metallic or pearlescent), for the minimum number of sparkle measurement. df: degrees of freedom; F: Ftest. Dash (–) indicates that there is no transformation. Superscript a indicates that the level of significance is $p < 0.01$.

Table 3. Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: metallic or pearlescent), for the minimum number of graininess measurement. df: degrees of freedom; F: F-test. Dash (–) indicates that there is no transformation. Superscript a indicates that the level of significance is: $p < 0.01$.

Table 1: Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: solid, metallic or pearlescent), for the minimum number of color measurement. df: degrees of freedom; F: F-test. Dash (–) indicates that there is no transformation. Superscript a indicates that the level of significance is $p < 0.01$.

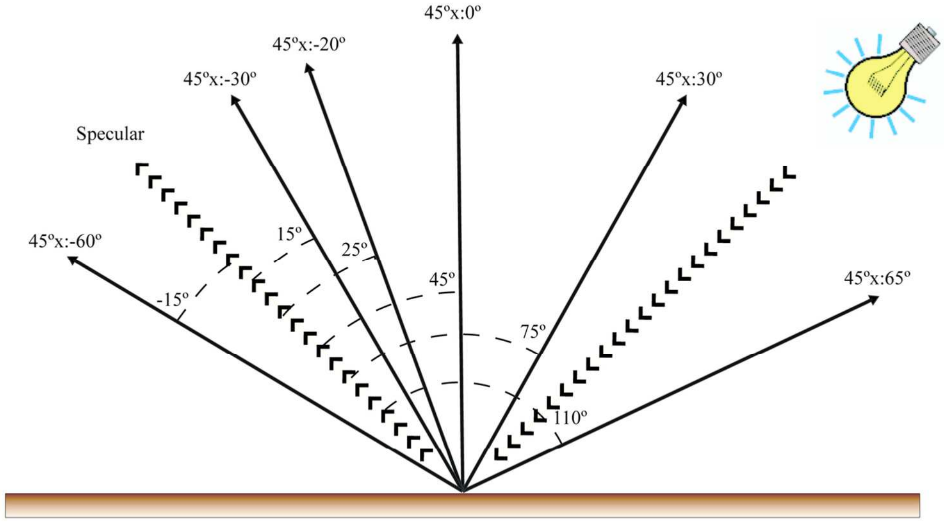
	-15º			15º		
	df	F	p-value	df	F	p-value
Type of pigment	2	1.1420	0.324[a]	2	0.0840	0.919[a]
Transformation		log(x+1)			-	

Table 2: Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: metallic or pearlescent), for the minimum number of sparkle measurement. df: degrees of freedom; F: Ftest. Dash (–) indicates that there is no transformation. Superscript a indicates that the level of significance is $p < 0.01$.

	15º			45º			75º		
	df	F	p-value	df	F	p-value	df	F	p-value
Type of pigment	1	6.3270	0.0147^{a}	1	0.0150	0.902^{a}	1	0.0850	0.772^{a}
Transformation		sqrt(x+1)			-			sqrt(x+1)	

Table 3. Results of analysis of variance (one-way ANOVA) (Factor - type of pigment: metallic or pearlescent), for the minimum number of graininess measurement. df: degrees of freedom; F: F-test. Dash (–) indicates that there is no transformation. Superscript *a* indicates that the level of significance is: $p < 0.01$.

	df	F	p-value
Type of pigment	1	7.3820	0.00867[a]
Transformation		-	



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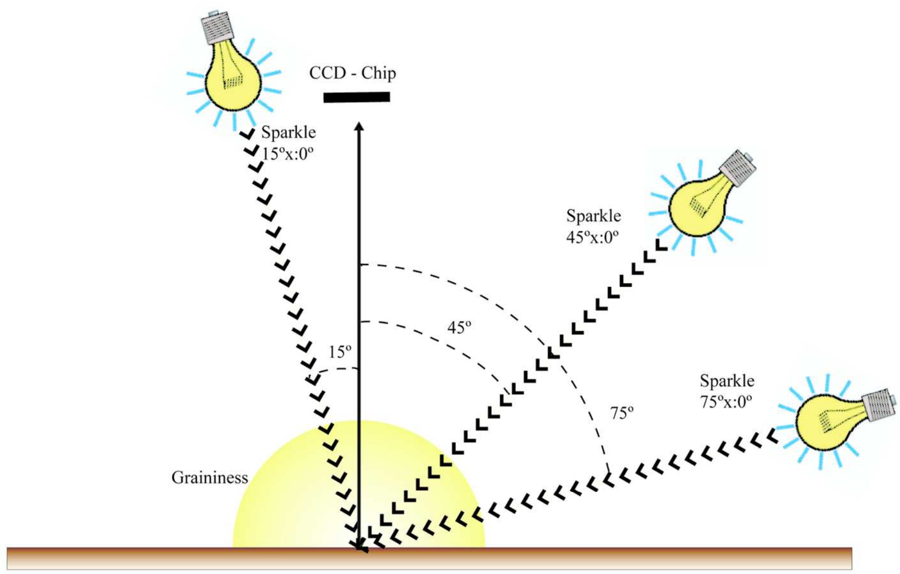

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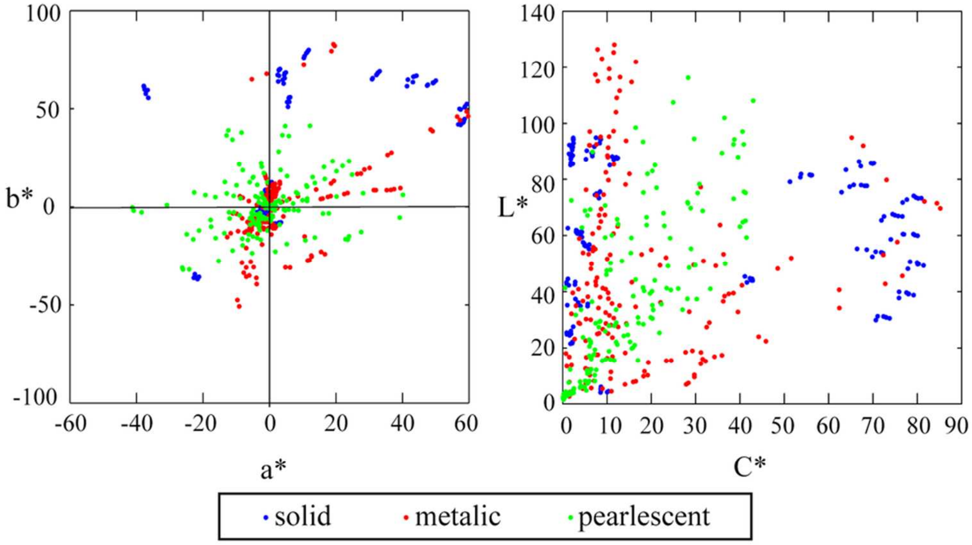

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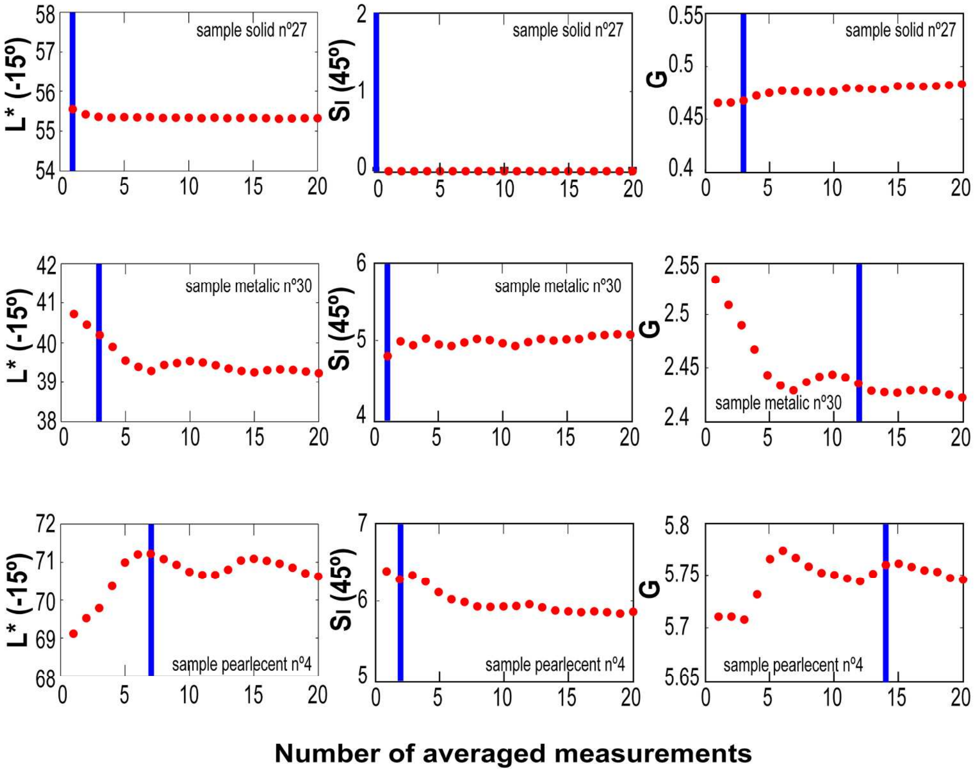

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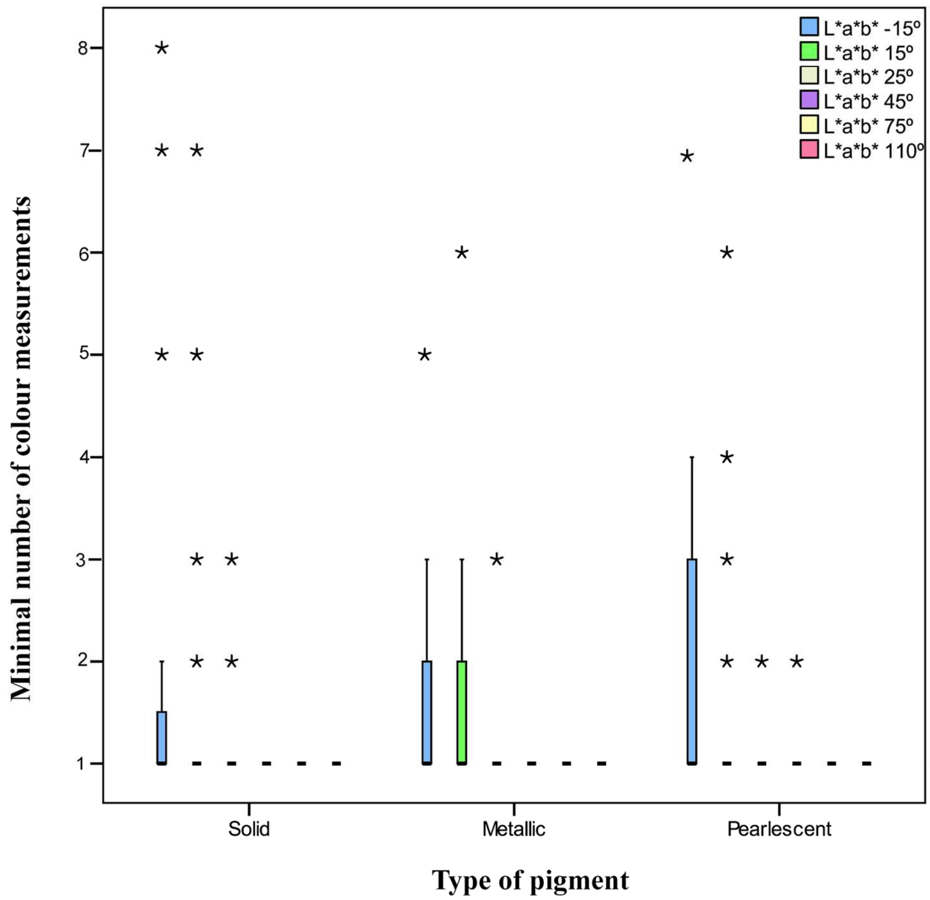

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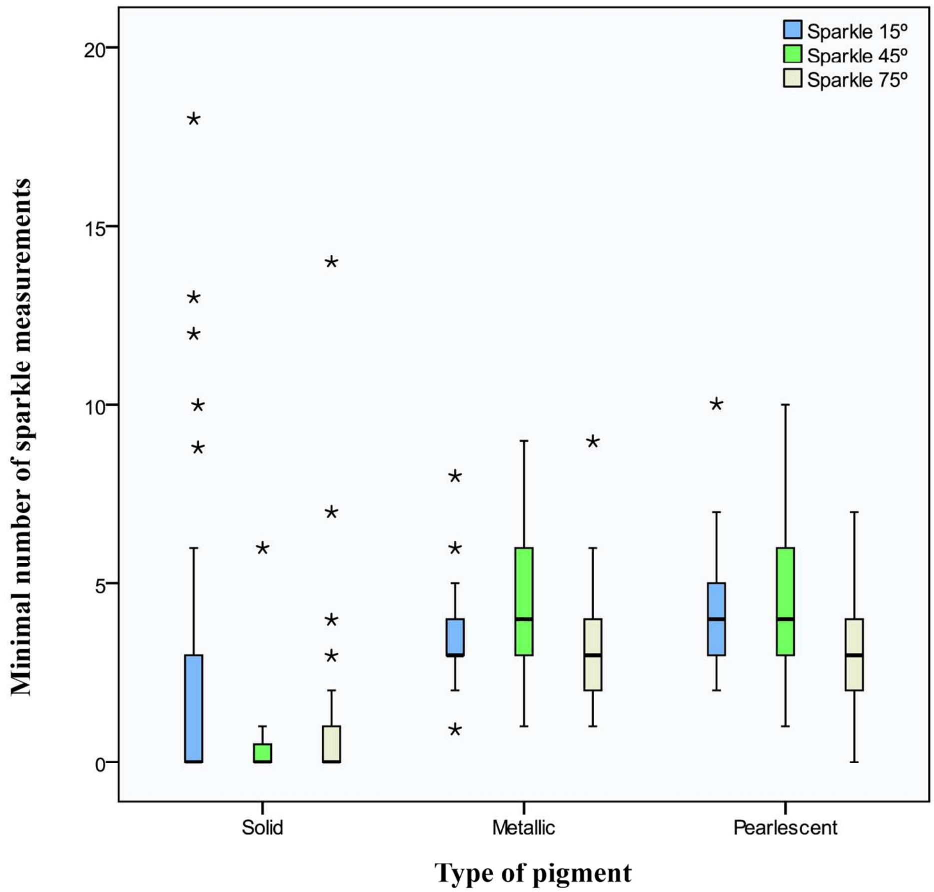

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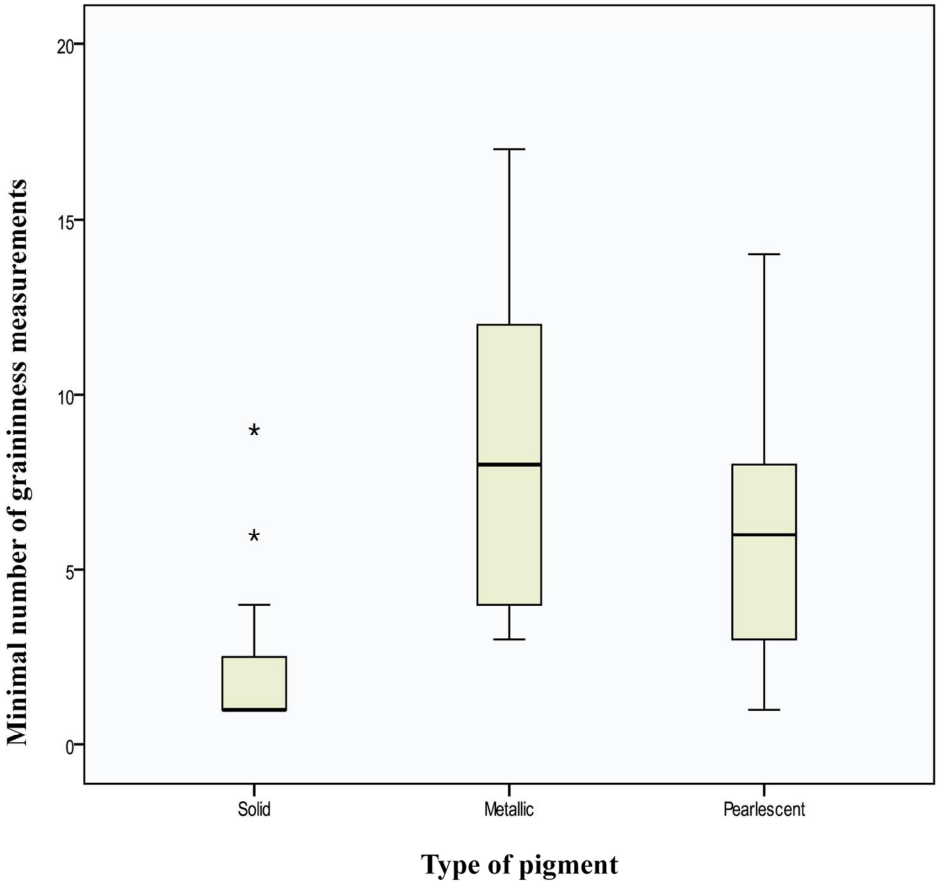

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