EUROPEAN COATINGS journal

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01-03 – 2025

# EASY TO SEE – TRICKY TO QUANTIFY

By Dr. Thomas Albrecht, Merck Electronics.

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# EASY TO SEE – TRICKY TO QUANTIFY

The optical fundamentals and the visual and metrological quantification of sparkle, caused by effect pigments in coatings.

By Dr Thomas Albrecht, Daniela Schier, Norbert Mezger and Dr Kirsten Fritsche, Merck Electronics, Surface Solutions.

**Sparkle is a complex optical phenomenon, the metrological characterisation of which has yet to be satisfactorily resolved. Visual sparkle characteristics of various silver-white pigments have been carefully quantified, but the results correlate poorly with established measuring methods. The sequel to this publication will describe new evaluation methods for sparkle patterns.**

Effect pigments not only give coatings attractive brightness- and possibly colour-flops, but also texture. The term "texture" is commonly used to jointly describe sparkle and graininess of an effect coating. Both effects are determined by the spatial distribution of effect pigments in the coating, their size distribution, reflectivity, and smoothness. The lighting and observation situation determines whether graininess or sparkle are visible primarily. Graininess relates to the mesoscopic brightness structure of an effect coating under diffuse lighting, which is visible at close range, e. g., under cloudy skies. If the light source becomes smaller, graininess transitions to sparkle [1] – small, bright spots of light that are best seen under direct sunlight, possibly up to a distance of a few metres. Unlike graininess, sparkle changes quickly depending on the geometry. If light source, object and/or observer move, sparkle becomes dynamic. Sparkle points light up briefly, disappear again and potentially appear to be moving over the surface.

Similar as for the colour of a coating, fast, simple, and precise measurement is desirable for its texture as well. This applies for coating manufacturers and paint shops, e. g. for colour matching. Pigment manufacturers such as Merck are interested in understanding the effects of their products in a coating as quantitatively as possible. Standardised measurands and measuring devices for the colour of coatings, including gonio chromatic coatings are well established. For texture, however, this is still largely lacking. The authors are only aware of three commercially available devices that can characterise the sparkle and graininess of effect coatings: the "Byk-mac i" (Device 1) from Byk-Gardner, the "MA-T12" (Device 2) from X-Rite and, a new product in the market, the "Aesthetix" (Device 3) from Rhopoint. Standardised measurands for texture do not yet exist. The JTC 12 technical committee of the International Commission on Illumination (CIE) is working on the definition of measuring methods and measurands for sparkle for several years. A preliminary method for characterising sparkle brightness has been published [2, 3], but this has currently only been tested on one pigment type (aluminium flakes) in nine samples from

## RESULTS AT A GLANCE

- → While size, reflectivity and colour of effect pigment particles are foundational for the sparkle of an effect coating, the visual impression is also determined by many other parameters.
- → In addition to the coating's properties, the geometry of illumination and observation or measurement plays a decisive role.
- → The sparkle characteristics of seven different silver-white pigments were determined visually in a semi-quantitative manner.
- → Most results are understandable and qualitatively consistent with pigment characteristics; colourists and stylists should find such results helpful for the precise adjustment of desired sparkle characteristics.
- → Commercial measuring methods do not reproduce the visual results well enough.

the "Standox Effect Navigator" [2]. Further experiments on more diverse sample sets are still outstanding.
A quantitative understanding of which pigment properties lead to which sparkle behaviour would be valuable for pigment and coating manufacturers. Therefore, a large number of experiments have been conducted with various pigment types using both, commercial measuring devices and custom setups.
This article, together with an upcoming article to be published, discuss, inter alia, why measuring sparkle is a challenge despite its easy visibility. Graininess is not a topic of the articles. This first part covers the basic optics of sparkle and visual results for a selection of common silver white pigments, as well as their correlation with measurement results from commercial instruments.

### SPARKLE CAN BE IMAGINED AS A "FOREST OF LIGHT CONES"

Sparkle is an effect that is not only determined by the paint, but to a large extent by the lighting and observation geometry. Why is that so? In the simplest case, a sparkle point is generated by a single pigment flake that is illuminated by a light source in such a way that the reflected light hits the eye or camera. Diameter and distance of the light source determine the angle of the light source subtended by the pigment particle. If the pigment particle were a perfect mirror, it would reflect a light cone with the same angular aperture. The emission direction is determined by its orientation in the coating. Flakes that lie exactly parallel to the coating surface reflect precisely into the glance angle. Their sparkles are lost in the specular reflection of the clear coat. Only disoriented flakes create sparkle points that can be seen around the gloss at aspecular angles. However, a pigment flake is not a perfect mirror and therefore widens its reflected light cone. This is due to bending und unevenness of the pigment platelets and to optical diffraction due to their small size. The widening effect depends on the pigment type and additionally varies from particle to particle.

Figure 1: Sketch of light cones that govern the visual appearance of sparkle. The cone arriving from the light source illustrates the angle subtended by the light source when viewed from an individual particle. The emergent light cones are all opened slightly further than the incident cone.

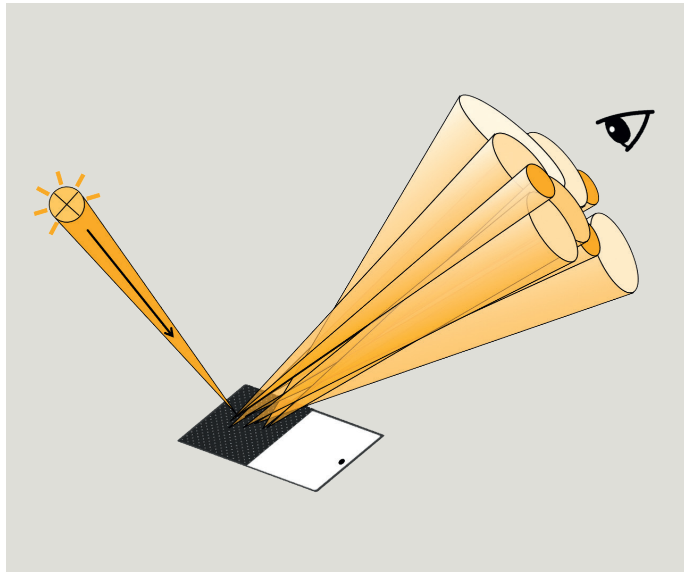
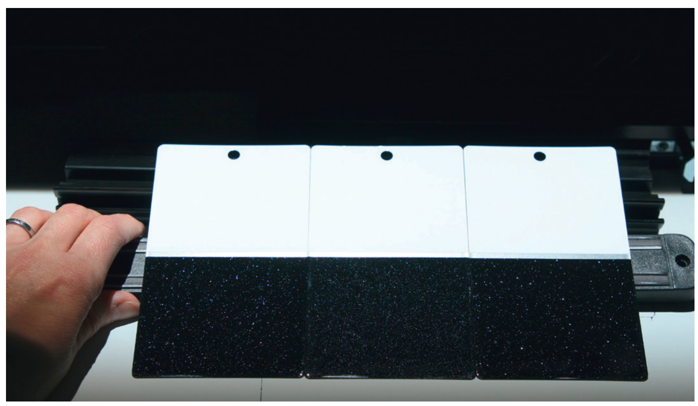


Figure 2: Three examples from the described panel series for illustration. (Sparkle is not only difficult to measure, but also hard to photograph and to reproduce as an image. The small size of sparkle spots and their high brightness ask too much of cameras, screens, and especially of printed materials.)



So, an effect coating illuminated by a light source that is small and far away enough, reflects a "forest of light cones" around the glancing angle, which an observer can see as sparkle. The quantity and brightness of sparkle spots seen by the observer depend on several factors, including the observer's viewing angle, distance, and the size of the entrance pupil (*Figure 1*). The range of angles over which a sparkle point is visible is called its "angular persistence".
The following parameters influence the perceived brightness of a sparkle point positively (+) or negatively (-):

- size, reflectivity and flatness of the pigment flake (+)
- angular aperture of the light cone assumed by the light source when viewed from the pigment particle (-)
- alignment of the reflected light cone to the entrance pupil (+)
- size of the entrance pupil (+)
- distance of the observer (-)

Table 1: List of silver-white pigments used, their substrates, oxide layers, sizes, PMCs, and the average brightnesses of the panels. A “single” oxide layer means a $TiO_2$ coating of the substrate; “multi” represents a $TiO_2$-$SiO_2$-$TiO_2$ layer sequence.

| Pigment data | | | Panel data | |
|---|---|---|---|---|
| **Pigment/ substrate** | **Oxide layers** | **Average particle area in µm²** | **PMC in %** | **L* (45°as15°)** |
| Corundum | Single | 170 | 0.056 | 11.2 |
| Natural Mica | Single | 190 | 0.025 | 8.8 |
| Glass flake 1 | Single | 650 | 0.065 | 8.3 |
| Glass flake 2 | Single | 590 | 0.13 | 11.6 |
| Silver Dollar | - | 160 | 0.0076 | 10.5 |
| Synthetic Mica ML1 | Multi | 290 | 0.030 | 9.4 |
| Synthetic Mica ML2 | Multi | 340 | 0.027 | 10.9 |

Under typical observation and measurement geometries, the size or even the shape of the pigment particles cannot be resolved. Like stars in the night sky, sparkle points can be taken as point sources. The perceived “size” of a sparkle point should correspond to its brightness and not be an independent parameter. Hence, this paper only refers to sparkle brightness.

With increasing viewing distance, sparkle points become darker and fewer. Firstly, the intensity of the reflected light declines roughly with the square of the distance. Secondly, a sparkle cone that is not perfectly aligned to the direction of observation, increasingly misses the entrance pupil as the distance increases. Thirdly, the contrast to the background decreases. A sparkle point is only visible when it has a certain contrast to the average brightness of the effect coating. As the brightness of the panel does not change depending on the distance, the sparkles become weaker and ultimately disappear in the background. (A point light source with a resolution-limited image in the eye or in a camera becomes darker as the distance increases. The image of an extended light source becomes smaller, but its brightness remains constant.)

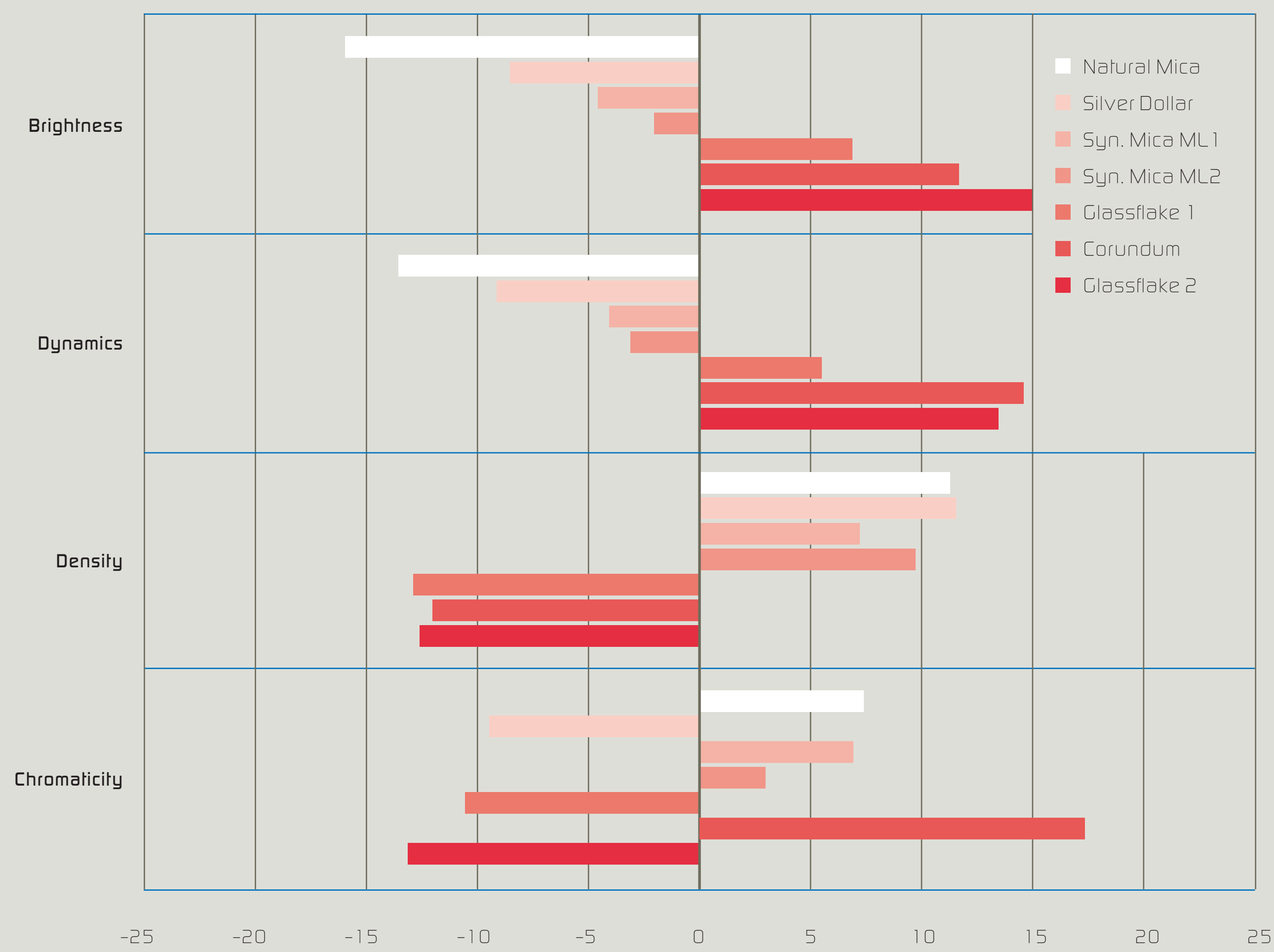
This qualitative discussion of “sparkle optics” has two objectives: Firstly, to make it easier to understand the following sections and secondly, to illustrate the complexity of the optical phenomenon and the large number of factors that influence sparkle. While colour can be measured from practically any distance and quantified easily by comparing to a white standard, this is not the case for sparkle.

## SEVEN DIFFERENT SILVER-WHITE PIGMENTS INVESTIGATED

Colourists, stylists, and pigment manufacturers have an interest in understanding which pigment types create which sparkle effects and whether these effects can be quantified. For example, the term “living sparkle” is copyrighted for the “Xirallic” product line. The exceptionally bright and dynamic sparkle is based on extremely planar, monocrystalline corundum substrates that barely expand the sparkle cones.

In order to compare the sparkle of various pigment types quantitatively, a series of seven test panels was manufactured. The system was kept as simple as possible by using pure effect pigments on a black substrate, i. e., no absorption pigments were added to the coating. So, every pigment particle is equally visible regardless of how deep it is located in the coating. It turned out that a very low pigment concentration, far below 1 % PMC (pigment mass concentration in dry film), was sufficient for a coating layer of 15 µm thickness, to create typical sparkle densities as seen in real-world, dark stylings. The refinish system coatings were applied to Leneta panels pneumatically. *Figure 2* shows three examples. A further advantage of the low concentrations is that the majority of pigment particles lie well separated in the coating. This means that seen or measured sparkle spots should predominantly originate from single particles, respectively.

Figure 3: Semi-quantitative results of the visual experiments.




Seven silver-white pigments were investigated, which are based on different pigment technologies and are known to have very different sparkle characteristics (see *Table 1*). The PMCs for the coatings were adjusted individually for each pigment such that all panels had a very similar brightness L* (45°as15°). This was important to improve comparability as observers cannot sensibly compare sparkle impressions of panels with significantly different brightness levels. For the instrumental determination of sparkle parameters, the similar brightness had the advantage that all sparkle pictures could be evaluated with the same brightness threshold. Only the black halves of the panels were observed and measured. Details of the examined samples can be found in *Table 1*.

Average particle areas were determined using an automated light-microscopy method that measures and counts particles with areas as of approx. 1 $\mu m^2$ upwards. In each case, 2,000 to 7,000 particles were measured, and the areas averaged. These average values are no good indicators for the pigments' "sparkle potential", however. The shapes of the size distributions differ strongly, especially in the fine particle range that is included in the average value. But sparkle behaviour is predominantly determined by the larger particles.

## VISUAL EXPERIMENTS: SPARKLE IS QUITE EASY TO SEE AND COMPARE

Two panels were compared side by side in a specially made observation box with defined illumination and observation geometry. The observers were asked to judge four sparkle parameters: brightness, chromaticity, density, and dynamics. The first three parameters were assessed at a fixed geometry. For sparkle dynamics, the panels tilted back and forth by a few degrees at a defined angular velocity. The observation distance to the panels was 68 cm.

In each case, the observer ranked the differences of the four parameters on a scale of -2 to +2. This was performed for every possible pairing of the seven panels in a random order without telling the observers which pigments they were seeing. Each pairing was matched twice, resulting in a total of 42 comparisons. A total of 15 observers took part in the experiments; the observers were diverse in terms of gender, age and "sparkle experience". At the beginning of the experiment, each observer was trained using several examples.

Aggregation and averaging of the data resulted in a value between -24 and +24 for each panel and each of the four sparkle parameters.

Figure 4: Reflected light microscopy images of the a) Corundum, b) Natural Mica, and c) Glass Flake 1 pigments showing the different chromaticities.

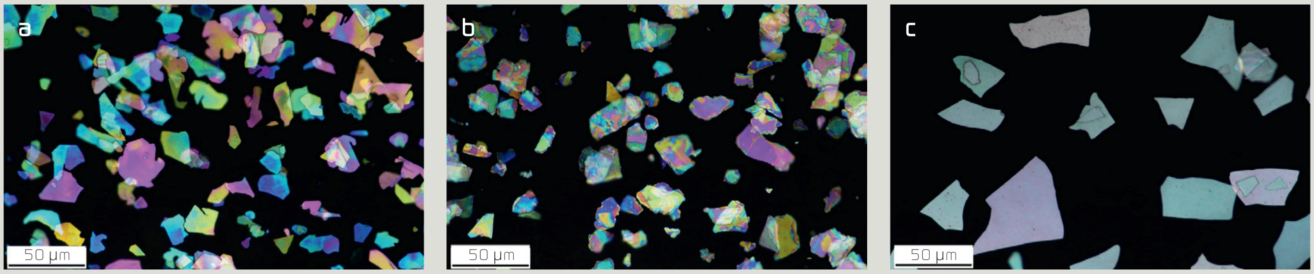



Figure 5a: "Byk-mac i" texture value $S\_i_{as15°}$ vs. visual brightness, seven measurements per panel. The small dots are single measurements, while circles represent the respective average values. The dotted line is a linear regression into the average values, yielding a poor correlation factor of just 0.43.

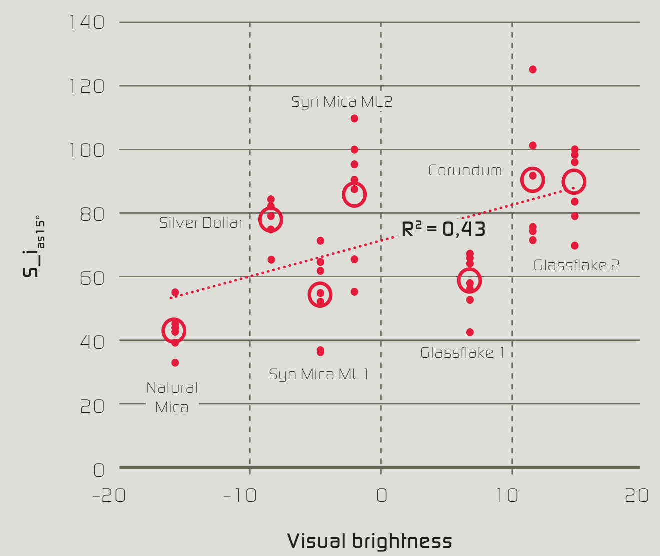
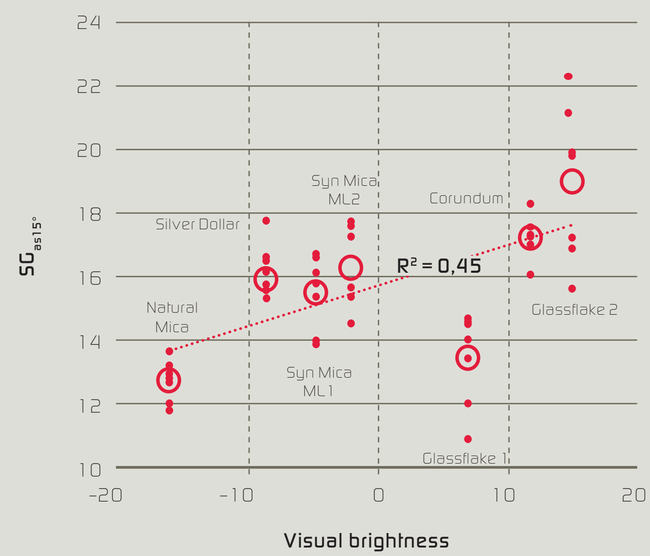



Figure 5b: Analogous to Figure 5a, $SG_{as15°}$ texture values from the "MA-T12" vs. visual brightness,




Results are displayed in *Figure 3*. The samples were sorted according to sparkle brightness results.

Sparkle brightness increases from natural mica over the silver dollar, the synthetic mica pigments to the glass flakes and corundum. The synthetic mica multilayer pigments presumably appear brighter than natural mica because the multilayer coatings reflect more strongly than the single layer on the natural mica. Despite only having a single-layer coating, the glass flakes appear brighter still because they are significantly larger on average than the mica pigments and aluminium flakes. In terms of brightness, the corundum pigment lies between the much larger glass flakes although all three pigments have a similar single-layer coating. The disproportionately high sparkle brightness of the corundum pigment is probably due to the evenness of the particles, which expand the reflected beam very little. Therefore, such a sparkle point remains brighter at greater distances than one with a more widened beam.

Surprisingly, sparkle dynamics correlates almost perfectly with brightness. Only the corundum pigment deviates slightly, appearing to be slightly more dynamic than would be expected from the brightness ranking. Originally, it was assumed that the dynamics or "liveliness" of the sparkle would depend strongly on the angular persistence of the sparkle and thus on the beam expansion power of the pigments. This should be quite different for the different pigment types. However, sparkle brightness appears to have a very dominant influence on the perceived liveliness.

Sparkle density correlates rather negatively with brightness. This is consistent with the approximately equal average brightness of the panels. Corundum and the glass flakes have bright sparkle points at a

lower density, while natural mica, silver dollar and the synthetic mica pigments show darker sparkle points at a higher density.
Sparkle chromaticity is independent of the other three parameters. The glass flakes and silver dollar show achromatic sparkle points, while corundum possesses the sparkle with the highest chromaticity. The colour of an interference pigment depends on the thicknesses of its coating and of the substrate. The thin $TiO_2$ layers of silver-white pigments do not produce an intrinsic colour; the particle colours are determined by the substrate thicknesses.
Glass flakes are so thick that they exhibit multiple interference maxima and minima over the visible spectral range. The human eye averages over these and sees almost white. On the other hand, the corundum substrates are so thin that they produce pronounced intrinsic colours. The ensemble of different-coloured flakes results in a white coating. However, the individual sparkle points generated by each particle are coloured. Unlike the corundum substrates, mica substrates typically have heterogeneous thicknesses. This causes colour variations within a particle, which can also be seen under a microscope. These mix together in a sparkle point to form a less chromatic colour. *Figure 4* shows a microscopic view of the discussed effects for three pigment types.
Sparkle chromaticity is a pigment characteristic that has proven robust against variations in PMC, observation geometry and distance in a number of further experiments. Chromaticity is even retained in black reduction. In the second article of this series, we will demonstrate that it can also be measured quantitatively. For sparkle brightness, however, this is not the case. It depends on all the influencing variables mentioned above and is therefore not a true pigment parameter.

## MEASURED VALUES FROM COMMERCIAL DEVICES DO NOT REFLECT THE VISUAL IMPRESSION OF SPARKLE BRIGHTNESS

As Device 3 was not yet available for the experiments, only the two established devices mentioned above were used: Device 1 captures black and white images for three different directed illumination geometries, from which it calculates the texture values sparkle intensity ("*S_i*"), sparkle area ("*S_a*"), and sparkle grade ("*S_G*") for each geometry. As Device 1 does not have a colour camera, it provides no information on sparkle colour. Device 2 captures HDR colour images for six different geometries, from which it calculates six sparkle grade ("*SG*") and colour value ("*CV*") values. The physical definitions of these parameters and the algorithms used to determine them from the images are unpublished.
The following is limited to the aspecular 15° geometry, which is most comparable with the geometry of the visual experiments – hence the "*as15°*" indices on the measured variables. In this, Part 1 of the article series, only sparkle brightness is discussed. Sparkle chromaticity will be discussed in Part 2.
It was found that the texture values scattered strongly and that several measurements per panel were necessary to arrive at sufficiently stable mean values. The large scattering of the individual values is presumably due to two factors: the special brightness statistics of the sparkles (discussed in more detail in Part 2 of the article series) and the devices' internal algorithms, presumably setting high thresholds for sparkle discrimination and thus detecting relatively few sparkle points per image. Also, the very low PMCs make this sample series special and possibly difficult to measure, although, as mentioned, the sparkle impression is not unusual for dark stylings.
Measurements were taken at seven different positions on each panel. As an example for Device 1 results, *Figure 5a* shows the $S\_i_{as15°}$ values plotted against visual brightness. *Figure 5b* shows the $SG_{as15°}$ texture values from Device 2 displayed in the same manner.
Neither the average $S\_i_{as15}$ values nor the average $SG_{as15}$ values from Device 2 correlate well with the visual brightness of the sparkle. The $S\_a$ and $S\_G$ values of Device 1 are not shown here for reasons of space. While $S\_a_{as15°}$ correlates well with the visual sparkle density ($R^2$=0.80), $S\_G_{as15°}$ does not correlate with our visual results ($R^2$ = 0.0 with visual sparkle brightness).
These findings are consistent with numerous other experiments as well as with statements of coating manufacturers, according to which the texture parameters of commercial measuring devices are at best meaningful for comparing highly similar coatings but usually cannot be correlated with the visual impression.

## CONCLUSION AND OUTLOOK

With careful sample design and systematic visual experiments, the sparkle characteristics of effect pigments can be compared well and evaluated semi-quantitatively. The results of visual experiments can help colourists and stylists select effect pigments to precisely control sparkle effects. However, visual experiments are time-consuming and only semi-quantitative. Therefore, a quick and easy way to measure the effects is desirable, which is unfortunately not yet possible with commercial equipment.
The sequel to this article will present that, in particular, sparkle chromaticity can be quantified very well from colour pictures. Also, progress on measuring sparkle brightness will be reported, at least for the present sample series.

## REFERENCES

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[2] A. Ferrero et al.; An insight into the present capabilities of national metrology institutes for measuring sparkle, Metrologia 2020, 57, 065029
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# EASY TO SEE – TRICKY TO QUANTIFY, PART 2

Analysis of sparkle images and correlation with visual impression. By Dr Thomas Albrecht, Daniela Schier, Norbert Mezger and Dr Kirsten Fritsche, Merck Electronics, Surface Solutions.

**Part 1 of this article series explained that sparkle is a complex optical phenomenon whose metrological characterisation has not yet been satisfactorily solved. Here in part 2, new evaluation methods for sparkle images are described that reproduce the visual perception of sparkle brightness and colour quite well.**

This is the second of two articles on the optical fundamentals and the visual and metrological quantification of effect coating sparkle. In the first part it was shown that a careful sample design and a systematic visual sampling allows us to compare and evaluate the sparkle properties of effect pigments semi-quantitatively [1]. Furthermore, it was found that texture parameters of commercial measuring instruments do not agree well with the visual sparkle impression. This second part describes new evaluation methods for sparkle images and demonstrates the quantitative measurement of sparkle brightness and sparkle chromaticity consistent with visual impression.

## CORRELATION BETWEEN DATA AND VISUAL IMPRESSION NEEDS IMPROVEMENT

Part 1 of the article series explained the visual experiments that are the basis for the following results. In order to quantitatively compare the sparkle of different pigment types, a series of seven test panels was produced (all silver-white pigments based on different pigment technologies, in very low PMC over black background. The PMCs were adjusted so that the panels had very similar medium brightness). In a specially designed observation box under defined lighting and observation geometry, the observers assessed four sparkle parameters: brightness, chromaticity, density, and dynamics. The results are semi-quantitative values for each of these parameters on a scale from -24 to +24.

As a reference for the following discussions and data, *Figure 1* shows the results of the visual sampling and *Table 1* contains the data of the sample series used.

Part 1 also showed that the texture values of commercial measurement devices do not represent the visual sparkle brightness impression well. Neither the $S\_i_{as15}$ values of the “Byk-mac i” (Byk-Gardner,

## RESULTS AT A GLANCE

- → The visual impression of effect coating sparkle can hardly be correlated with texture values measured using commercial measuring instruments.
- → This applies to both the sparkle brightness and chromaticity.
- → New methods have been developed to extract sparkle brightness and chromaticity from images that correlate well with the visual impression.
- → Sparkle chromaticity has been shown to be fairly stable against measurement geometry and PMC and that it is a characteristic parameter for a pigment.
- → Sparkle brightness is very sensitive to these and other influencing factors and is therefore not a real pigment parameter.
- → Therefore, identical geometry of the set-ups for observation and measurement is a prerequisite for matching measurement and visual impression of sparkle brightness.

hereinafter referred to as Device 1) nor the $SG_{as15}$ values of the “MA-T12” (X-Rite, hereinafter referred to as Device 2) correlate well with sparkle brightness data from the visual experiments.

### SPARKLE-POINT BASED IMAGE ANALYSIS YIELDS GOOD RESULTS

Since Device 2 provides photometrically correct HDR images (see example in *Figure 2*), it is not immediately clear why it should not be possible to determine parameters from these that correspond to the observed sparkle brightness. Therefore, we developed our own image evaluation software to flexibly analyse sparkle images. It does not simply evaluate pixel-based, but discriminates and analyses individual sparkle points, each consisting of several pixels. The software makes it possible, e. g. to manually set the threshold for sparkle discrimination, to measure the brightness of individual sparkle points as the sum of all associated pixels or simply as the value of the brightest pixel. It can analyse brightness and colour distributions and calculates mean values etc. from these. In the following, we use the CIE Yu′v′ colour space and, accordingly, Y as a brightness measure.

### SPARKLE BRIGHTNESS

The analysis of the brightness distribution of sparkle points provides an approximately exponential distribution. As an example, *Figure 3* shows the distribution of sparkle brightness for the Natural mica and the Corundum panels (seven “MA-T12” images were aggregated for each data set). All images were evaluated with a brightness threshold of $Y_{th}$=30 and the brightness of the respective brightest pixel ($Y_{max}$) was used as a brightness measure for each sparkle point. Each data point corresponds to the number of sparkles in a bin of width $\Delta Y$=15. ➜

Figure 1: Semi-quantitative results of the visual experiments (from Part 1).

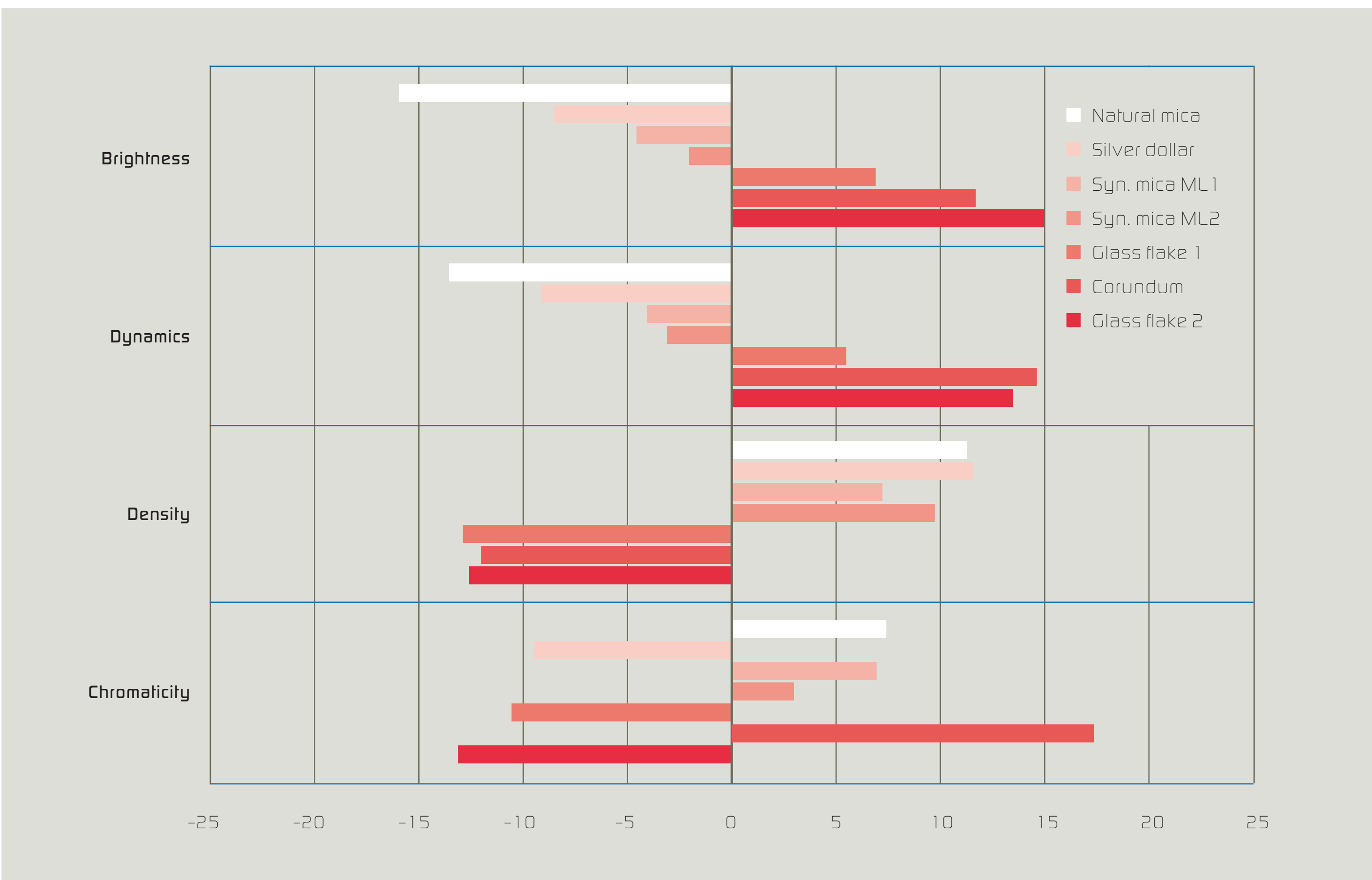


Table 1: List of the silver white pigments used, their substrates, oxide layers, sizes, PMCs, and medium brightnesses of the panels. A 'single' oxide layer means a $TiO_2$ coating of the substrate, 'multi' stands for a $TiO_2$-$SiO_2$-$TiO_2$ layer sequence.

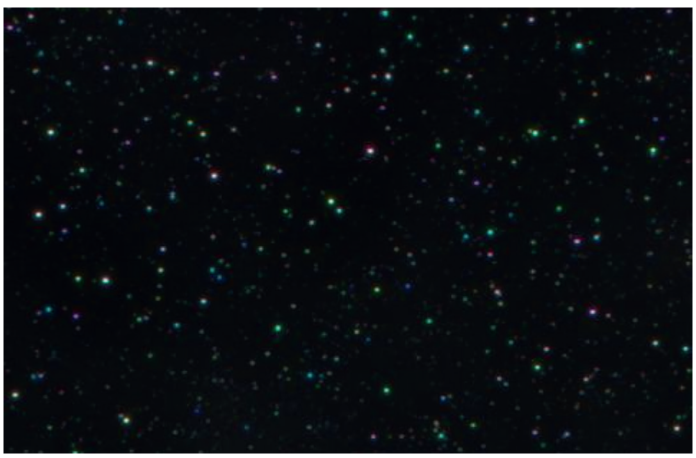
| Pigment/substrate | Oxide layers | Mean particle area in µm² | PMC in % | L* (45°as15°) |
|---|---|---|---|---|
| Corundum | Single | 170 | 0.056 | 11.2 |
| Natural mica | Single | 190 | 0.025 | 8.8 |
| Glass flake 1 | Single | 650 | 0.065 | 8.3 |
| Glass flake 2 | Single | 590 | 0.13 | 11.6 |
| Silver dollar | – | 170 | 0.0076 | 10.5 |
| Syn. mica ML1 | Multi | 290 | 0.030 | 9.4 |
| Syn. mica ML2 | Multi | 340 | 0.027 | 10.9 |

One finds brightnesses of $Y_{max}$ > 500, which is only the value for the brightest pixel. In images from Device 2, however, a sparkle dot is composed of several pixels. Adding up their brightness values, a multiple of the $Y_{max}$ value is obtained for a sparkle spot. This is one of the reasons why the CIE-L*a*b* system appears unsuitable for analysing sparkle brightness. The L* scale is only defined for matte colours on macroscopic surfaces up to L*=Y=100. If the brightness goes far beyond that, and the light source is a microscopically small sparkle point against a dark background, the nonlinearity of the human eye is probably different from what is assumed in the L*a*b* system. Therefore, the linear quantity *Y* is used here.

Exponential distributions are skewed and, in many ways, less 'well-behaved' than more usual symmetric distributions such as the Gaussian normal distribution [2]. Many more data points are needed than with a normally distributed variable to reduce the mean error of the average into an acceptable range. Experimentally, it is found that even a few particularly bright sparkle points can significantly shift the mean value. However, one cannot ignore them as outliers, since the eye also perceives the brightest sparkle points particularly strongly and includes them as a dominant part of the visual impression.

A single Device 2 image of the samples 'only' contains approximately 100-300 sparkle points. For a Gaussian-distributed measurand, this would be considered more than enough to determine the mean value accurately. Here, however, it turns out that the mean values fluctuate significantly from image to image, similarly to the texture values discussed in part 1 [1]. Therefore, the data from seven images were aggregated for the following analysis. The distributions shown in *Figure 3* contain approx. 800 (Natural mica pigment) and approx. 900 (Corundum pigment) sparkle points. The lines correspond to exponential distributions shifted by $Y_{th}$ with the mean values of the measured data.

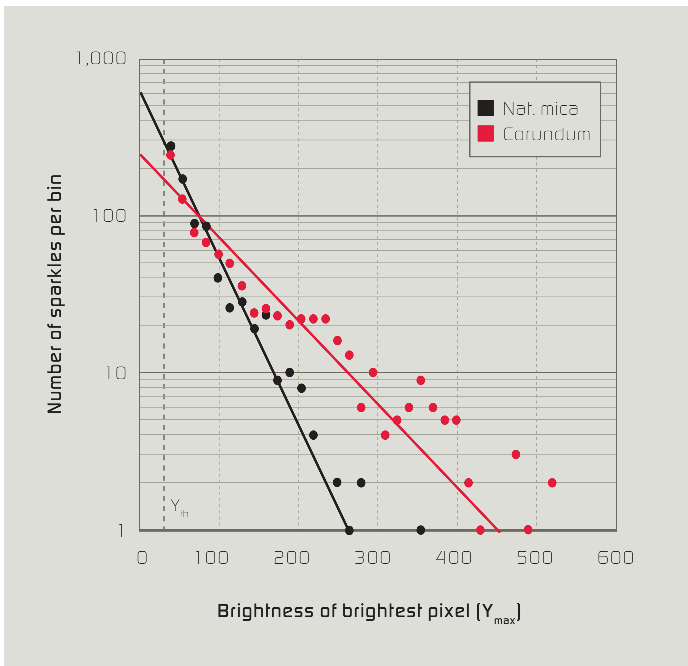
Figure 2: "MA-T12" image in the geometry r15as15 (i.e.: 15° observation angle, vertical illumination, 15° aspecular angle) of the corundum pigment panel. The measuring field is 9 x 12 mm.



## CHOOSING THE BRIGHTNESS THRESHOLD FOR SPARKLE ANALYSIS

The sample series discussed here could be evaluated using a common threshold, $Y_{th}$. The threshold was chosen empirically in such a way that it did not strongly influence the results and that there was

Figure 3: Sparkle brightness distributions of two panels. Seven "MA-T12" images of each panel were aggregated (Threshold $Y_{th}$=30, bin size ΔY =15).



a good correlation with the visual data. A higher or lower $Y_{th}$ shifts the average brightness values in the same direction (for precise exponential distributions even by the exact amount of the shift of $Y_{th}$). The results shown below are qualitatively robust against a variation of $Y_{th}$ by at least +/- 10 units.

A general method for measuring sparkle brightness requires a method to calculate a suitable $Y_{th}$ from the average brightness of the sample and, possibly, the brightness of the brightest sparkle points. This has not yet been developed. Such a method would have to be tested with a large, diverse set of samples. The literature [3] describes an algorithm that is based on the determination of the brightness of the weakest, just visible sparkle points and sets the threshold there. This method, too, still needs to be validated using more experiments with more diverse samples. Experience has shown that the brightest sparkle points dominate the visual impression. Whether the eye averages linearly over the full brightness scale down to the visual limit, has yet to be proven.

*Figure 4* shows the mean sparkle brightnesses of all samples, derived from "MA-T12" images, for a common $Y_{th}$=30. The data correlate very well with the visual brightness from *Figure 1*. The correlation is surprisingly linear. Linearity was not to be expected, as the human eye reacts nonlinearly to brightness in various ways, and also the semi-quantitative nature of the visual data does not guarantee linearity. So, it can be empirically stated that the described method corresponds very well to the perception of the human eye.

## LIGHTING AND OBSERVATION GEOMETRY ARE CRITICAL FOR SPARKLE BRIGHTNESS

Despite the good correlation, the visually determined order of brightnesses is not perfectly reproduced by the measured data. In particular, the sparkle of the Corundum pigment is seen brighter than measured. The reason for this deviation is probably the different beam expansion of the different pigment types and thus the influence of the observation distance. This concept was discussed in the first part of the article. The hand-held measuring devices measure from a few centimetres away, while the observation distance of the visual experiments was about ten times greater.

To investigate this hypothesis, the panels were photographed with a consumer camera in exactly the same geometry as the visual experiments and the images were evaluated as described above. These experiments reproduce the visual results of the brightness sequence exactly and, depending on the evaluation, correlations of up to $R^2$=0.97 can be achieved with the data! However, the results are only preliminary and rather qualitative. The camera does not show a linear brightness curve, its dynamic range is too limited, and it is difficult to avoid over-exposure of the brightest sparkle points. Further experiments are planned using a luminance camera.

The three pigments sparkling the brightest have very different average particle sizes. The average particle surface areas of the two Glass flake pigments, measured using light microscopy, are three to four times larger than that of Corundum (see also *Table 1* and microscope images of pigments in *Figure 4* of [1]). Although all three pigments have a similar, single, silver-white $TiO_2$ coating, the sparkle brightness is obviously not proportional to the particle area. This shows once again that the flatness of the pigment and possibly other influencing factors significantly influence sparkle brightness.

Conclusion for sparkle brightness:

- You can measure what you see, but only from the same distance and in the same lighting and observation geometry!
- Sparkle brightness is not a parameter that would characterise a pigment because it depends on too many other factors.

## SPARKLE CHROMATICITY AS A PIGMENT PROPERTY

The chromaticity of sparkle is not expected to depend on the observation distance. Therefore, it should be possible to extract this parameter from colour images produced by Device 2 in a way that is consistent with observation from a greater distance. However, the colour parameter $CV_{as15}$ from Device 2 does not correlate well with the visual

Figure 4: Correlation of mean sparkle brightness from seven "MA-T12" images per panel with visual brightness. Error bars are mean errors.

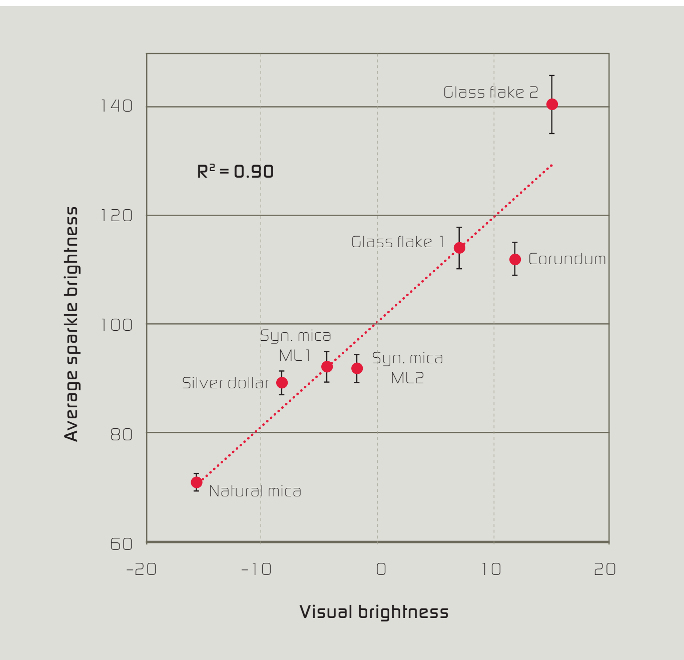
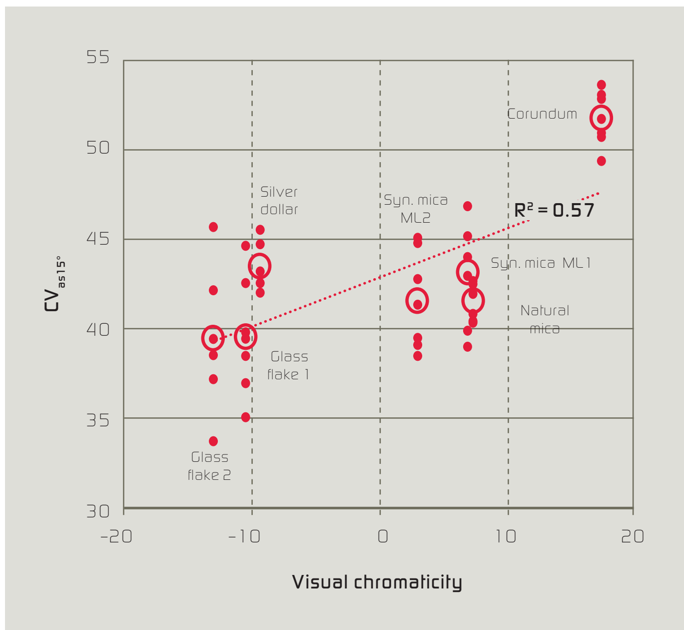



Figure 5: Correlation of the "MA-T12" colour values (CV) for the geometry r15as15 with visual chromaticity. Each panel was measured seven times (small dots) and the results were averaged (circles).



experiments (*Figure 5*). $CV_{as15}$ values are quite large even for the three samples with neutral sparkle and grow only moderately with increasing visual chromaticity. In addition, the individual measurements are strongly scattered, similarly to the S_i and SG values shown in part 1 of the article.

The above-mentioned image analysis program calculates the colour of each individual sparkle point by taking an average of all its pixels. It can display the colours of all sparkles contained in one image as a "point cloud" in the u'v' colour space *(Figure 6*). The size of such a cloud has proven to be a good parameter for sparkle chromaticity.

**Figure 6: Sparkle colour clouds in u´v´ for the chromatic corundum and the neutrally sparkling glass flake 2 with ellipses of the principal component analysis. The black asterisk is the white point.**

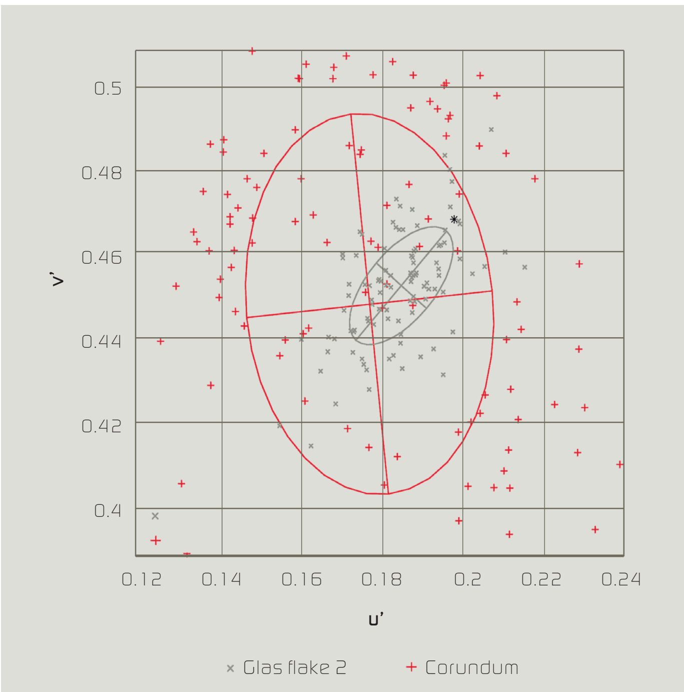
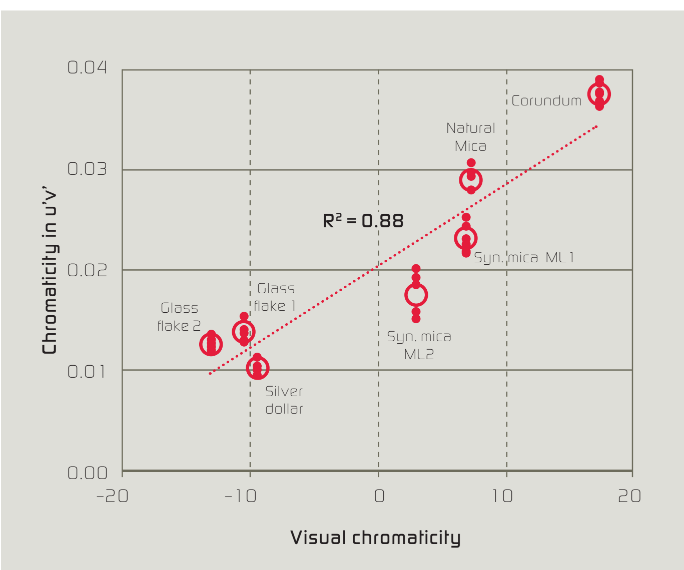



**Figure 7: Correlation of the measured and visual sparkle chromaticity of the seven pigment types. Dots are individual measurements, circles the respective averages.**




The size of a point cloud is analysed by a main component analysis [4]. In *Figure 6*, the centres of the ellipses are the respective averages of the data, the axes are the directions of the main components, the axis lengths are the standard deviations of two-dimensional Gaussian distributions fitted to the point distributions. The mean value of the axis lengths is defined as the chromaticity parameter.

*Fig. 7* shows the good correlation of these measured chromaticity parameters (again from seven "MA-T12" images of each panel) with the visual chromaticity of *Fig. 1*. The clear distinction between neutral sparkle (Silver dollar and Glass flakes) and chromatic sparkle can be seen. The ranking of the chromaticity of the four pigments with chromatic sparkle is also consistent with the visual impression. It can also be seen that the individual measurements don't scatter much. Sparkle chromaticity can therefore be analysed from just a single "MA-T12" image.

Unlike sparkle brightness, chromaticity is quite robust against changes in PMC or viewing distance or the addition of carbon black (data not shown). Thus, the measured sparkle chromaticity is a texture parameter that can actually be called a pigment property.

## NEXT STEPS TOWARDS REAL-WORLD COATINGS

The presented investigations show that it is quite possible to measure the sparkle brightness of effect pigments in such a way that the results are consistent with the visual impression. This requires the same illumination and observation geometry, including the same distance for measurement and observation. Sparkle chromaticity is a pigment property and can be determined from colour images from commercially available measuring devices.

Some of the results not discussed here are still preliminary and are the subject of current work. For example, even for the very small PMCs used, the average sparkle brightness is not PMC-independent. An increase in particle density results in brighter sparkle points. This effect is most likely caused by two or more particles lying so close together that they form a single sparkle point. This effect and its influence on the sparkle brightness distribution needs to be investigated and modelled in more detail.

As a first step toward real-world coatings, the experiments are currently repeated using black reductions. Absorption has an analytically predictable influence on the shape of the brightness distributions, which will be tested. The next steps are experiments with coloured effect pigments and finally with real car paints.

A method for setting the brightness threshold for sparkle discrimination analytically, which works for all paints, has yet to be developed.

In addition, the sparkle dynamics is of particular interest. The aim is to understand which physical properties of a pigment and a paint determine the visual impression of dynamic sparkle.

## REFERENCES

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[4] https://en.wikipedia.org/wiki/Principal_component_analysis, date of access: 13.12.2024

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