Perceived Effects of Static and Dynamic Sparkle in Captured Effect Coatings

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***Abstract*—Quality control applications in the coating industry characterize visual properties of coatings containing effect pigments using glint impression, often denoted as sparkle. They rely on a collection of static images capturing sparkle properties of pigment flakes. However, visual characteristics of pigment flakes are highly correlated to their material properties and their orientations in coating layers. Thus, while two effect coatings can exhibit similar static sparkle behavior, their dynamic sparkle behavior may be very distinct. In this paper, we analyzed the perception of static and dynamic sparkle using two psychophysical studies on 38 effect coatings and 31 human subjects. First, we have shown a good agreement between the perception of sparkle in real specimens and in photographs. Second, we observed significant differences in perceived static and dynamic sparkle. Our results demonstrate a need for a multiangle recording of sparkle when assessing effect pigment visual characteristics.**

***Index Terms*—effect pigment, sparkle, appearance, measurement, video**

I. Introduction

Texture of visible pigment particles is one of the most important features of effect coatings characterization. Although there is a missing standard on coating texture measurement and analysis, the industry has been using texture features for quality control purposes routinely for almost a decade now. One of these features describing glint impression of coating texture called *sparkle* is related to a number of sparkling particles visible for a fixed directional illumination. A correct characterization of sparkle is important for quality control process of effect coating production. E.g. in automotive industry different parts of car body are made from fifferent materials but should have the same appearance regardless different coating systems used. Fig. 1 shows an example of an unacceptable sparkle difference.

Glint behavior can be recorded either statically using photographs or dynamically using video for different view or camera orientations. Although there has been wide use of sparkle in industry, its relation to computational visual qualities of effect coatings is unknown. Therefore, in two psychophysical studies we:

- compared differences in sparkle perception of 38 effect coating specimens and their photographs,
- compared differences in sparkle perception between static and dynamic recordings of effect coatings.

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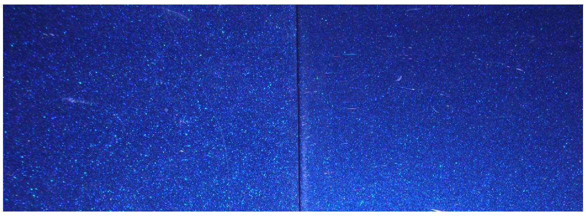

Fig. 1. Two coatings with different sparkle properties.

II. Related Work

A detailed overview of special effect pigments is given in [1] and [2].

Several research papers demonstrate a gradual expansion of research knowledge on the spatial analysis of effect coatings. Kirchner et al. [3] used a psychophysical test to identify glint impression under either diffuse or directional lighting as an important texture features of effect coatings. They have shown that a trained observer can distinguish between 8 and 10 levels of such features with high mutual consistency. Observers' repeatability and reproducibility was around 0.5 on an eight-point scale. Huang et al. [4] proposed a method predicting total visual differences of effect coatings based on variations in color, coarseness, and glint. The method depends on the type of illumination used. Rentschler [5] has shown a systematic variation of sparkle for different effect pigment types and particle sizes. Dekker et al. [6] psychophysically analyzed color, sparkle and used this information to derive a total appearance difference equation. Ferrero et al. [7] proposed to study contrast and density of sparkle spots at different illumination/observation geometries to establish the sparkle characteristic of a specific coating. While contrast is determined by the specular reflectance of flakes, i.e. by their size and diffuse reflectance of the coating, density is determined by the orientation distribution of flakes and their flatness. Kirschner and Ravi [8] overviews recommended color and texture tolerance appropriate for use in the automotive industry. As for coating texture, they report a sparkle grade parameter introduced by BYK-Gardner, defined as the geometrical mean

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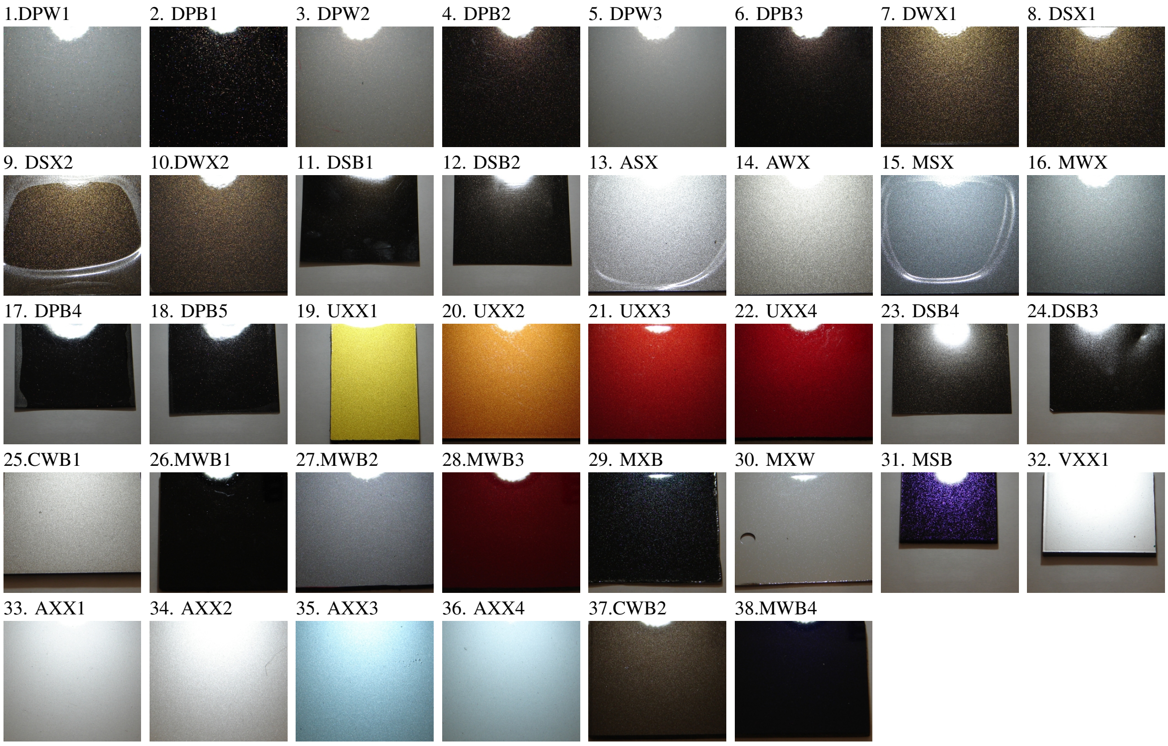

Fig. 2. Photographs of the 38 tested coatings for a pointlight illumination.

of sparkle intensity and sparkle area. Kirchner et al. [9] borrowed from astronomy and used methods for predicting the number of visually distinguishable flake intensities. Winston et al. [10] ran several psychophysical studies to validate sparkle reading of a commercial device BYK-mac [11]. Seubert et al. [12] analyzed the relationship between flake orientation and coating appearance and created a model of scattering behavior of metallic paint systems [13].

Wang and Luo [14] performed perceptual studies of glint impression and fitted the psychophysical data to reading of the BYKmac instrument [11]. They also analyzed dimensionality of glint space using multi-dimensional scaling, where two main dimensions correspond to sparkling intensity and sparkling area. They suggest that glint impression is highly related to particle size, which is a predominant factor controlling sparkle intensity, alongside with full width at half-maximum extracted from multi-angle dense BRDF measurements. Iacomussi et al. [15] psychophysically analyzed sparkliness of mica-based pigment of different particles distributions under different illumination conditions and compared the results with reading of the BYKmac instruments.

Methods of psychovisual analysis of material appearance were focused to perceptually driven compression [16] and filtering [17] of bidirectional texture functions. We are not aware of any psychophysical analysis of low-dimensional effect coatings representation operating in a spatio-angular domain.

Initial methodologies for coatings characterization in the seventies and eighties suggested only between two and four geometries sufficient for the characterization of coatings showing solid color [18]. With the onset of effect pigments, more geometries turned out to be necessary. Development converged resulting in acceptance of the standard ASTM E 2539–08 [19] that was subsequently extended to ASTM E 2539–12 [20]. Two industrial instruments capable of sparkle measurement have been introduced in the last decade: BYKmac and MA-T12.

We are not aware of any study systematically comparing differences between static and dynamic visual perception of effect coatings.

III. Tested Coatings

For purpose of our analysis we collected a set of 38 effect coatings featuring different pigment types, coating systems and basecoat colors. We assigned each sample a unique identifier consisting of three letters. The first letter defines pigment type (A - aluminum, M - mica, C - combine aluminum and mica, D - diffractive, U - ultra-thin pigment (UTP), V - vacuum metalized pigment (VMP)). The second letter defines coating system used (S - solventborne, P - powder, W - waterborne). The third letter defines basecoat color (B - black, W - white). If the information is not available we use letter X. Photographs of the coating panels captured for point-light source are shown in Fig. 2.

IV. Methodology

We assessed sparkle of the test effect coating samples within two psychophysical studies. In both studies subjects observed the samples and evaluated perceived sparkle on an eleven-point Likert-like rating scale, where 0 corresponds to the lowest and 10 to the highest intensity. This range should represent only the span of materials within the study, i.e., the highest rating of sparkle should correspond to the material having the highest sparkle effects from the study and not from the real world. We adapted this design as it is dominant in image and video experiments [21].

The subjects rated sparkle separately for each material. To make perceptual scaling tasks easier, each stimuli contains all evaluated samples. Subjects were between 22 and 54 years of age, had normal or corrected vision and were naive with respect to the purpose of the experiment. All subjects reported normal or corrected-to-normal visual acuity. As we are interested in analysis of sparkle phenomena, we have not tested observers color vision. Subjects received a compensation of the equivalent of $8 for their participation in the study.

Experiment 1 – Real Specimens For the first experiment, we used 38 real samples placed on the table with corresponding numbers as shown in Fig. 3. Sparkle was evaluated for directional illumination (approximately 45° from surface normal) using a single warm-white LED lamp (1521 lumen, 2700K) and blinded window. Subjects were free to move around the samples and could move the samples but not the lighting. There was no time restriction on the task. A total of 20 untrained subjects participated in the experiment. Each session of all samples took typically 15 minutes.

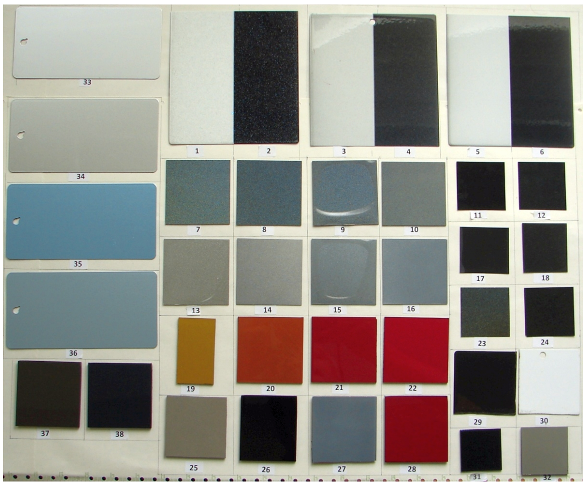

Fig. 3. Table with materials as viewed by subjects.

Experiment 2 – Specimen Recordings In the second experiment we used images and video of the same samples obtained by a goniometer with 16Mpix RGB camera. The camera's sensor distance from the sample was 2m, and we used a resolution of 353 dpi (i.e., $67\mu m$/pixel). We used in-plane geometry with viewing polar angle $\theta_v = 45°$ and five illumination polar angles as shown in Fig. 4. We used these illumination angles so as to obtain the same differences between viewing and illumination directions as those used in commercial devices measuring sparkle. Relative angles to viewing direction were -15°, 15°, 45°, 60°, and 75°, i.e. polar angles -60°, -30°, 0°, 15°, 30°. Additionally, we included also a video showing recordings of all 38 samples for different in-plane illumination angles ranging from -75° to 75°. We

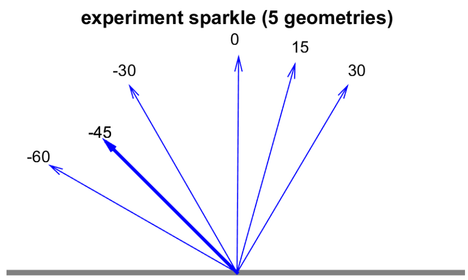

Fig. 4. Geometries used for sparkle analysis in experiment 2 (camera is at position -45°).

captured images of each material sample for each of the five geometries. Then photographs of all 38 tested samples were compiled into one large image of a resolution 1920×1080 pixels, where each sub-image corresponds to approximately 16mm squared of real specimen. Examples of stimuli images for sparkle are shown in Fig. 5. The stimuli images were

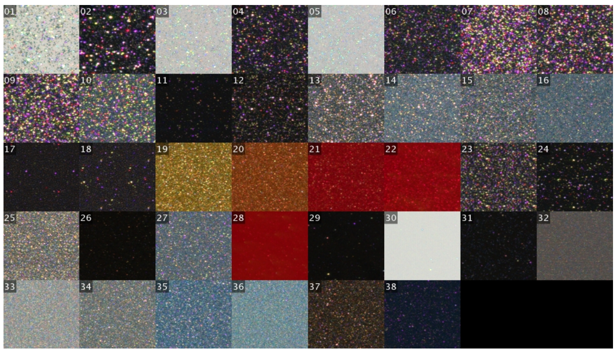

Fig. 5. Examples of stimuli images for sparkliness for $\theta_i = 0°$ (right).

shown on a 24" colorimetrically calibrated monitor Iiyama XU2492HSU (resolution 1920×1080 pixels, maximum luminance 250 cd/m2). Subjects assessed sparkle of individual captured samples on a scale 0-10. There was no time restriction in completing the task, and a total of 11 untrained subjects participated in the experiment. Each session, i.e. evaluation of five geometries of static sparkle and one movie for dynamic sparkle of each sample typically took 60 minutes.

V. A Psychophysical Evaluation of Real Specimens – Experiment 1

Prior to data analysis, we checked on the presence of outliers and assessed agreement across subjects. First, we performed outliers rejection by removing values differing from mean subject responses for more than 5 scale points. A total of 15 outliers were found representing 1.0% of 1,520 values recorded in the study.

Next, we checked subjects' responses agreement using Krippensdorff alpha [22] – a statistical measure of the agreement generalizing several known statistics. The key requirement is agreement observed among independent observers. Output α_K = 1 represents unambiguous indicator of reliability, while 0 does not. The α_K value was 0.783, demonstrating good agreement among the subjects.

We also analyzed the significance of differences between samples' means using hypotheses testing of means of individual samples using Kruskal-Wallis and repeated-measures ANOVA. The obtained p-values below 2e-7 demonstrate a high significance.

To get insight into typical subjects' responses, we computed the mean opinion score (MOS) obtained as average rating across all subjects. This is standard methodology for a subjective quality assessment used particularly in the audio and video industries, and recommended by standard international organizations such as ITU [23] or ISO [21]. The mean opinion scores ranging from 0 to 10 and tested materials are shown for sparkle in Fig.6 in blue. The error bars in the graphs represent standard error values.

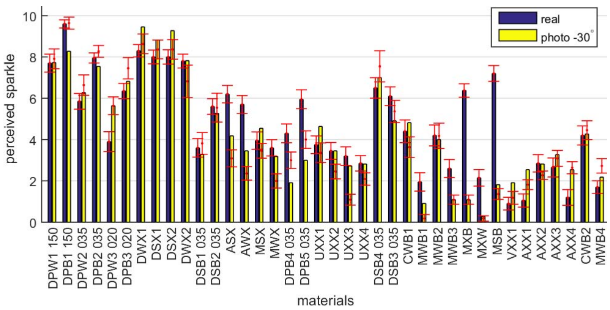

Fig. 6. Values of sparkle obtained in experiments with real samples and their photographs for illumination polar angle $\theta_i = -30°$.

VI. A Psychophysical Evaluation of Captured Specimens – Experiment 2

Also in the experiment assessing samples' photographs, we performed first outlier detection, with 32 outliers representing 1.3% of 2,508 values recorded in the study. The Krippensdorff alpha values computed for sparkle at different geometries α_K =0.790, 0.765, 0.610, 0.599, 0.494 demonstrated decent agreement among subjects particularly for the first two geometries. Repeated measures ANOVA hypothesis test has also shown a high significance of results, with p-values below 3e-9 for all tests. The computed mean opinion score values are

TABLE I
A correlation of perceived sparkle between experiments using real samples and their photographs for viewing polar angle $\theta_v = 45°$.

	correlation coef	p-value	mean std. err.
static $\theta_i = -60°$	**0.787**	0.0000	1.27
static $\theta_i = -30°$	**0.774**	0.0000	1.25
static $\theta_i = 0°$	0.684	0.0000	1.65
static $\theta_i = 15°$	0.331	0.0421	1.75
static $\theta_i = 30°$	0.616	0.0000	1.91
dynamic	0.466	0.0032	1.74

shown, alongside values from the first experiment, in Fig. 6 in yellow. For sparkle, the main differences were recorded for mica-based samples (MXB, MXW, MSB) where sparkle perceived from photographs was much lower than from real samples. Some differences are also present for some aluminum pigments (ASX, AWX) and two diffractive pigments (DPB4, DPB5). This was probably caused by the limitation of our camera resolution, as it was not able reliably record sparkle of very small, isolated pigments. Additional reason can be a limited dynamic range of the monitor used in the psychophysical experiment.

VII. Relationship between static and dynamic sparkle

To relate sparkle perception in specimens and their photographs, we analyzed data from both pychophysical studies. We computed correlations between results of both experiments. Tab. I shows Pearson correlation coefficients computed between results of both experiments (including p-values). We observe high correlations (r=0.77,0.78) for the first two sparkle geometries (see Fig. 4), i.e., $-60°$, $-30°$. Therefore, in Fig. 6 we show results for illumination geometry $\theta_i = -30°$, which is also commonly used in industrial instruments. The last column in Tab. I shows standard error values obtained for all subjects observing captured samples, averaged across all samples. Again these errors were the lowest for illumination geometries $-60°$, $-30°$. Relatively high correlation numbers demonstrate that the capturing process can reliably convey sparkle information from effect coatings. Our analysis also shows that close to retro-reflective illumination angles have lower standard errors than near-specular illumination angles.

In contrast, we observe a very low correlation between real specimens and their dynamic representation for different illumination angles (see the last row of Tab. I). This might be due to different observation scenarios of real samples, where subjects slightly moved viewing position while illumination was fixed, while in stimuli this was vice versa. This difference in perception of real speciment and dynamic stimuli motivated us for further analysis and therefore, we focused on perceived sparkle in captured data only. We compared perceived sparkle effect in captured data between static stimuli (the one having the best perceived agreement with the real samples, i.e. $\theta_i = -30°$) and dynamic stimulus (a range of illumination elevations $(-75°, 75°)$). Such a comparison is shown in Fig. 7, where we can observe clear differences for all samples save for 16 diffractive ones. For all other coating samples, the values

TABLE II
A CORRELATION OF PERCEIVED SPARKLE IN DYNAMIC AND STATIC STIMULI FOR VIEWING POLAR ANGLE $\theta_v = 45°$.

	correlation coef	p-value
static $\theta_i = -60°$	0.570	0.0002
static $\theta_i = -30°$	0.716	0.0000
static $\theta_i = 0°$	**0.832**	0.0000
static $\theta_i = 15°$	**0.825**	0.0000
static $\theta_i = 30°$	0.593	0.0001

of perceived sparkle were much higher for dynamic than for static stimuli.

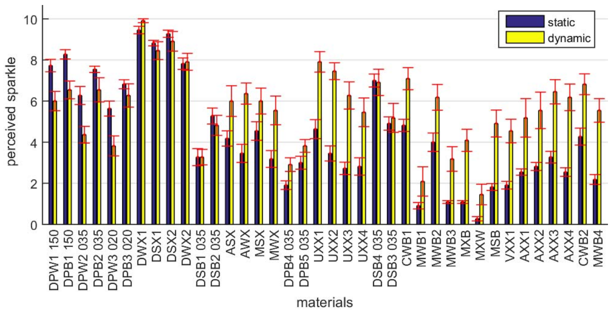

Fig. 7. A comparison of perceived static ($\theta_i = -30°$) and dynamic sparkle over the test dataset.

Further, we compared correlations between dynamic and static sparkle for five tested illumination directions (see Tab. II). Our results showed that the highest correlation values (r=0.83) were obtained for illumination directions close to a sample surface normal, i.e. $\theta_i = 0°$ and $15°$. When analyzing captured images for these illuminations, we observed the highest number of sparkling particles for these two configurations. Their number even increased for the near-specular configuration $\theta_i = 30°$, but for some materials this effect was visually masked by high intensity of specular highlight, therefore perhaps explaining a drop of correlation to only 0.59 for this last configuration.

To sum up, our analysis on 38 effect coating samples has shown that dynamic sparkle is more correlated with sparkle captured closely to specular highlight, i.e. configuration having significantly more visible sparkle flakes. When compared to a static sparkle, in our configuration it have maximal correlations shifted approximately 30° in illumination polar angle towards specular highlight. These observations suggest that when multi-angle setups or video is used as additional source of sparkle information, it should focus on illumination angles ranging from retro-reflection to specular reflection.

VIII. CONCLUSIONS

Our study compared differences in perceived sparkle effect in effect coatings using different pigment materials, coating systems, base colors and pigment sizes. We used a set of 38 samples and performed psychophysical studies on real specimens and their image-based recordings using a goniometric setup. Our comparison has shown a positive agreement between results obtained from both studies, and demonstrate that captured data can serve as an accurate representation of real specimens. Using this data we have shown that there are high differences between perceived static sparkle obtained as image and dynamic sparkle obtained as a collection of images for different illumination polar angles. This supports the importance of a multiangle measurement configuration for the proper identification of sparkle properties of effect coatings.

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