Workshop on Material Appearance Modeling (2019)
H. Rushmeier and R. Klein (Editors)

On Visual Attractiveness of Anisotropic Effect Coatings

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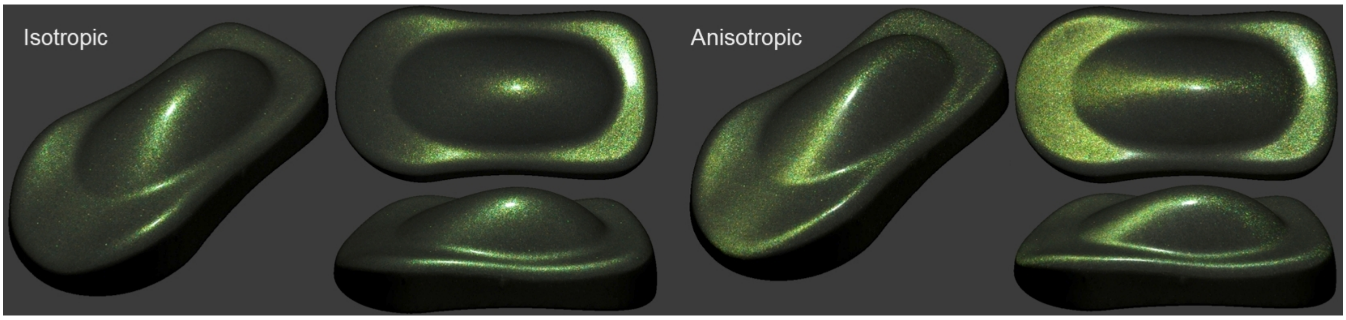

Figure 1: *A comparison of magnetic pigment captured as isotropic SVBRDF (left) and anisotropic SVBRDF (right) for point light from top.*

Abstract

With the global trend in customer preference towards achromatic car colors, color designers in coating industry strive to create novel design-critical appearances based on novel effect pigments. At microscopic scale, the pigment particles allow to create specific optical effects like sparkle under directed lighting along with a specific texture in diffuse lighting, while at a macroscopic scale they create the appearance of angle-dependent color and a strong luminance contrast. Although individual particles in effect coatings exhibit anisotropic behavior, the majority of effect coatings exhibit isotropic appearance at a macroscopic scale due to a random orientation of the particles which can be explained with the manufacturing process of the coating. This paper demonstrates an visual appearances achievable by using anisotropic effect coatings based on magnetic pigments. In a psychophysical study, we assessed visual attractiveness of these coatings on a car-like shape for different viewing angles.

1. Introduction

Automotive, electronics and cosmetics industries have widely adopted effect pigments in coatings, to enhance the visual attractiveness of their products. Effect pigments are also often used in printing inks or 3D printing filaments that allow artists or those in graphics to create eye-catching posters and objects. Effect pigments particles are typically flat elongated flakes. Their shape, material, or orientation in media, related to coating application, determine a final visual appearance of the coating.

The standard coatings based on effect pigments [MPR05], [Pfa08], i.e., effect coatings, have typically non-uniform azimuthal distribution of particles orientations. However, this non-uniformity is, except specific security applications [AS04], strictly kept on a level which is not visible to a standard observer. In context of this paper, we consider that these coatings have close to random distribution of flakes' azimuthal orientations in a basecoat, causing globally isotropic appearance variations. At microscopic scale, the pigment particles allow to create specific optical effects like sparkle under directed lighting along with a specific texture in diffuse lighting. In contrast, at macroscopic scale they create the appearance of angle-dependent color and a strong luminance contrast. The texture effects due to effect pigments are usually visible from several meters; therefore, the visually correct representation of spatially-varying information is essential for its reproduction.

Effect pigments are frequently used to underline and enhance the 3D-object shape (i.e., concave / convex structures) in automotive car bodies, where the overall appearance is closely matched to a car shape. Thus, the development of effect coating can take years, requiring experienced designers and colorists. Designers choose different base coating colors, flakes distribution sizes, layer thickness, or a pigment deposition process to control the final appearance of the car body. While current industrial coating application procedures can control and predict the inclination of flakes within the coating layer relatively well, they cannot easily orient them uniformly in a particular azimuthal direction. Due to this random azimuthal distribution of flakes, designers can achieve the same ap-

DOI: 10.2312/mam.20191310

pearance at a macroscopic level regardless of the rotation of the material. We call this constant azimuthal behavior, isotropic.

In this paper, we build on our recent work on analysis of attractivenes of anisotropic reflections on a car body shape [FK18]. But instead of anisotropy simulation using a BRDF model, we captured SVBRDF of two coatings containing magnetic pigment allowing to control anisotropy direction. We visualized the captured data on a car body shape and analyzed its visual attractiveness as a function of anisotropic axis alignment (see Fig. 1). To address this task we ran a psychophysical experiment obtaining human judgments for different observation directions.

2. Related Work

Effect pigments can be, based on the principle of chroma and sparkling effect generation, roughly divided into three categories [MPR05], [Pfa08]: metallic , interference, and diffractive pigments. Metallic pigments rely mainly on geometrical properties of flakes and their reflectance, interference pigments introduce effects due to light wave interference with transparent substrate coated with materials of high refractive indices, and diffraction pigments decompose light at a diffraction grating of a frequency close to the wavelength of the incoming light. Note that in practice many effect coatings are often combinations of the above classes. Lans et al. [LKH12] presented an empirical approach to the realistic modelling of special effect flakes fitting patch-based model parameters using sparse texture data obtained by a portable multi-angle spectrophotometer. In [RSK09] were presented extensions towards gonioapparent coatings texture measurement and modelling using bidirectional texture function (BTF) [DvGNK99]. Pereira et al. [PLMR17] suggested fabrication of printing custom based anisotropic BRDFs by using a time-varying magnetic field and photo-cured resin. In [Fil15] was shown that material anisotropy produces a more visually attractive appearance.

Our recent work [FK18] has shown that car body observers systematically prefer a certain orientation of anisotropy axis regardless of the surrounding illumination. This work deal with specific anisotropy type, i.e., effect coating containing magnetic pigments that create strong azimuthally dependent effects. We are not aware of any work psychophysically analyzing captured and visualized spatially-varying appearance of anisotropic effect coatings.

3. Tested effect coatings

To create a test set of anisotropic coatings, we used two different magnetic pigments in powder. A composition of the powder and resin was applied using cylindrical film applicator (see Fig. 2-left) to create uniform layer of thickness approximately 100μm. As a base material, we used 2 mm thick plastic sheet with black glossy basecoat. Although powder manufacturers suggest using UV-curable resin, undercuring occured, so we resorted to a standard waterborne resin. For this resin the solidification process took slightly over 10 seconds. This time window was sufficient to unify the orientation of pigment particles by swiping a neodymium magnet under half the painted area.

Applied coatings are shown in Fig. 2-middle,right. In the image

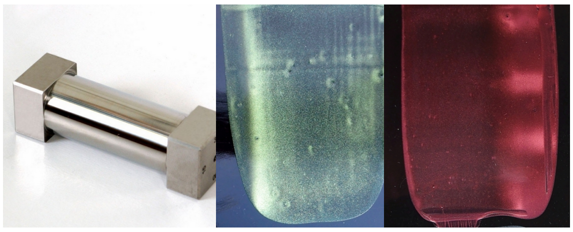

Figure 2: *Cylindrical film applicator (left) and two tested pigments applied on a plastic material with black glossy basecoat (middle, right).*

there are apparent boundaries due to the magnet being swiped under a part of the coating. An interesting finding was that particles are oriented, i.e., not randomly scattered, already after the application, without need of application of the magnet. This is probably due to the fact that pigments are magnetic, and they are already uniformly oriented by the swiping of the metal applicator above the coating layer.

Fig. 3 shows how the appearance of individual pigment particles changes due to a change of illumination direction.

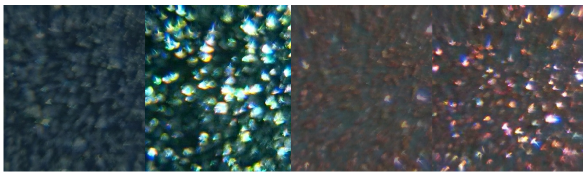

Figure 3: *Microscopic images of the pigment flakes for two illumination directions azimuthally 90° apart.*

4. Samples capturing

In the next step, we captured the spatially-varying appearance of these four samples using a half-difference parameterization [Rus98]. As suggested in [FV19] we fixed the azimuthal angle of illumination direction owing to the half-direction at $\varphi_d = 0^\circ$, and thus we sampled three angles $\theta_h \times \theta_d \times \varphi_h$. This section compares the reconstructed SVBRDF data using the proposed anisotropic framework with full captured anisotropic SVBRDF dataset $\theta_h \times \theta_d \times \varphi_h$ of $18 \times 5 \times 24 = 2160$ images. Captured BRDFs obtained by averaging of SVBRDF images are shown in Fig. 4 showing clear anisotropic behavior along φ_h. To obtain a reference isotropic ap-

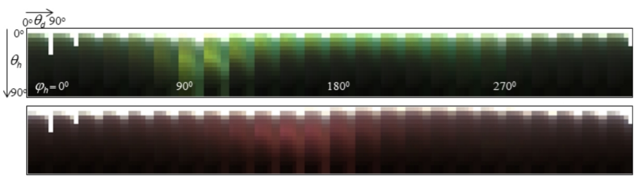

Figure 4: *BRDFs of captured anisotropic samples.*

pearance, we use the bivariate subspace for a fixed φ_h having the closest intensity to mean intensities of all such subspaces along φ_h.

For each pair of incoming and outgoing directions in both slices, we captured a HDR image of the measured material of resolution

42μm/pixel. We used a four-axis gonioreflectometer for capturing the angular-dependent appearance of coatings. The size of the captured sample was 40×40 mm, distance of the camera was 2 m, and distance of the light, 1.5 m. The device was geometrically and colorimetrically calibrated, and the measured flat sample normal was accurately aligned within the coordinate system of the device. Due to our experimental application method, the appearance of the coating was not uniform across the entire sample. Therefore, we manually selected an uniform area of 150×150 pixels (corresponding to 6.3×6.3 mm) in the captured images that was cut out. As some of the selected areas still were not entirely spatially uniform in hue and luminance, we carefully removed their lowest frequency components in Fourier space. Individual texture tiles are stored in an uncompressed binary format and are directly accessed using lookup functions in our OpenGL rendering application. A linear interpolation is used for the obtaining of non-measured directions. We used a linear interpolation from the two closest directions along each dimension.

5. Analysis of attractiveness

We ran a psychophysical study to identify the most visually attractive orientation of anisotropy axis over a car-shape. We used four different views, while the point light was fixed over the car-shape. To make the study tractable, we preselected six different orientations of anisotropy (0°,30°,60°,90°,120°,150°). We used a car-like shape viewed from front-side, lateral, top, and front directions. To adjust visual scales in both experiments, subjects were shown renderings of all orientations in a single stimulus (as shown in left and middle column of Fig. 5). They were asked to adjust rating slider for each rendering. The stimulus contained images for different anisotropy orientations accompanied with rendering for isotropic appearance in a random order. The subjects were asked to rate visual attractiveness on a Likert scale ranging from 0 (the least attractive) to 6 (the most attractive) with 3 as neutral. In total 23 anonymous subjects participated in the the online study. Each session took in average two minutes.

After the experiment we computed mean opinion scores to obtain graphs of perceived attractiveness as a function of anisotropy orientations shown in Fig. 5-right. Constant outlines in the graphs correspond to the captured bivariate isotropic representation.

While for the green coating the anisotropic appearance was considered as more attractive than isotropic (see the constant lines), for the red one it was the other way round. Although the patterns of anisotropic highlights were similar, subjects prefer brighter highlights of the green coating. Interestingly, while for lateral, top, and front views we observe for both coatings more-or-less similar subjects' judgments, for front-side view we see distinct behavior. Stimuli images reveal that subjects preferred evenly illuminated front and rear part of the shape. Similarly to [FK18], subjects prefer alignment of anisotropic highlight symmetrically along the lateral axis of the car-body, as shown in the results for the top view. For the front view we observe almost constant response for green coating, while the red coating demonstrates more changes in appearance. This might be due to lower intensity of anisotropic highlights for red coating, where the specular highlight visually prevails. Our study demonstrates, that:

1. (1) Effect coatings with controlled pigment orientations can introduce novel attractive appearance (see Fig. 1).
2. (2) Not all anisotropic coatings are perceived as attractive. This is possibly related to color of the coating and luminance/color contrast of the anisotropic highlights.

6. Conclusions

We captured spatially-varying appearance of effect coating containing magnetic pigment to create anisotropic effects. The captured data were visualized on a car shape for point-light illumination and several view-points. In a psychophysical study was studied to what extent the captured anisotropic appearance impacts perceived attractiveness of a car body over standard isotropic appearance of effect coatings.

Acknowledgments

This research has been supported by the Czech Science Foundation grant GA17-18407S.

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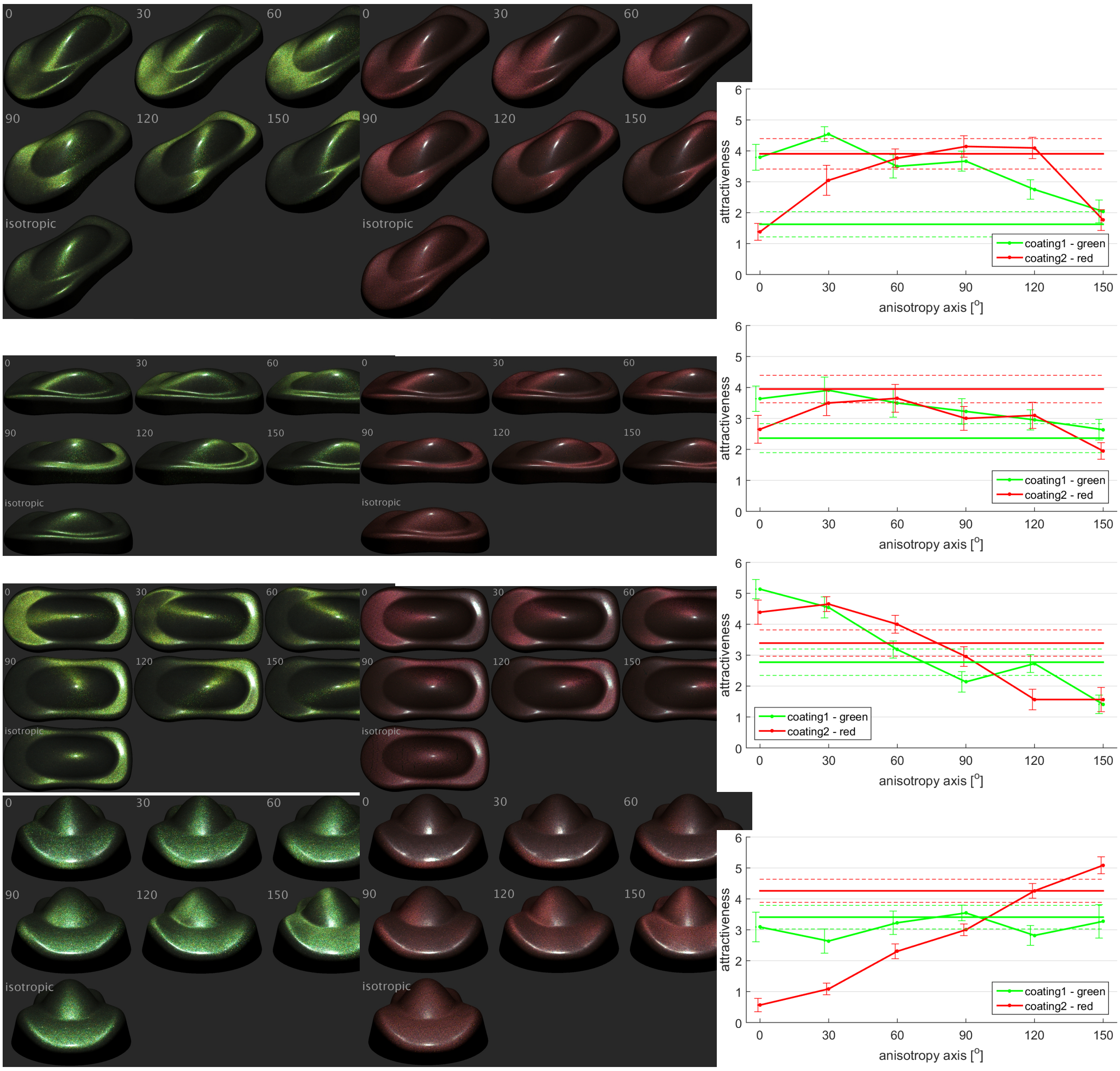

Figure 5: *Object appearance for different views and top illumination as a function of anisotropy axis orientation (left) and (middle) and their perceived attractiveness (right). Constant outlines depict attractiveness of isotropic appearance. Error-bars and dashed outlines represent standard errors.*