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Effect of surface texture on color appearance of metallic coatings

S. Amookht [a], S. Gorji Kandi [b,*], M. Mahdavian [a]

[a] Institute for Color Science & Technology, Tehran, Iran
[b] Polymer Engineering and Color Technology Department, AmirKabir University of Technology, Tehran, Iran

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ABSTRACT

In this study, the effect of aluminum flake size on the color appearance of metallic coatings has been investigated. To this end, metallic solvent-borne basecoat-clear coat systems with seven different surface textures using different sizes of aluminum flakes were prepared corresponding to nine color centers including blue, yellow, red, green, purple, cyan, orange, greenish yellow and gray. The color changes via texture differences were assessed by visual experiments carried out by 25 observers including 14 women and 11 men using gray scale method and under semi-diffuse illumination conditions. The assessed pairs had the same color center and different visual texture caused by different aluminum flake sizes. Texture analysis was performed using autocorrelation function and fractal dimension on gray scale images of the samples, captured by a scanner, and texture difference for each assessed pair was computed.

The results showed that different aluminum flake size can cause different visual texture and consequently different color appearance. The correlation between perceptual color differences and the texture differences showed that autocorrelation function and fractal dimension have a pretty good performance for quantifying texture feature of the metallic coatings while the texture is caused by aluminum flakes.

1. Introduction

Appearance is visual perception which is evaluated in terms of attributes or specific visual qualities object. The appearance attributes are divided in color and geometric attributes. Geometric attributes such as haze, gloss and distinctness of image are created by the object geometry including shape, size and texture [1]. Texture refers to properties that represent surface or structure of an object and consist of texture primitives or elements which are a contiguous set of pixels with some tonal and/or regional property and can be described by its average intensity, maximum or minimum intensity, size, shape, etc. [2]. Texture analyses which are mathematical procedures are generally used to characterize the texture of objects [3].

Special effect coatings such as metallic and pearlescent coatings are well known for their texture attributes. There are two comprehensive reviews that describe appearance of the coatings including texture [4,5]. In some studies, designed instruments (for example texture camera and micro-spectrophotometer) were used to measure texture properties such as sparkle, glitter and microbrilliance, and process image for special effect coatings instrumentally [6–8]. Extended studies were made to correlate the observed texture, which is called visual texture, to the measured physical parameters, e.g. diffuse coarseness and glint impression [9,10]. The diffuse coarseness and glint impression were defined to aid the color matching process for effect coatings [11]. Also, using a new instrument that was developed partly on the basis of the correlation with visual data, the effect of texture on the perceived appearance differences was quantitatively investigated which led to a total appearance difference formula [12]. In addition, there are studies which investigate the effect of texture on the color for other industries, e.g. textile. Considering a new term to evaluate texture difference of a pair of textile samples, the perceptual and instrumental effects of texture on color was investigated [13].

In former studies, image analysis or correlation of visual perception is considered on gray coatings [6–12] while in this study, we will focus on measuring texture differences of pairs of metallic coating samples using image processing and has been attempted to correlate it to the visual appearance difference via texture variation of metallic coatings.

2. Experimental

2.1. Sample preparation

All samples are metallic solvent-borne basecoat-clear coat systems and were prepared in two groups using different sizes of cornflake-type aluminum flakes produced by Benda-Lutz (Austria),

* Corresponding author. Tel.: +98 2164542431; fax: +98 216413969.
E-mail address: s.gorji@aut.ac.ir (S. Gorji Kandi).

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Table 1
Seven metallic coatings with different flake sizes.

Sample	Flake size (μm)
M1	26.44
M2	29.41
M3	33.78
M4	59.69
A	%75M1:%25M4
B	%50M1:%50M4
C	%25M1:%75M4

while formulation was constant, i.e. constant PVC values. The first group contains metallic coatings with four different sizes of single flakes. The flake size distributions were measured by a MASTERSIZER 2000 particle size analyzer. The means of flake sizes are 23.98 ± 0.41 μm, 26.91 ± 0.42 μm, 31.37 ± 0.34 μm and 56.72 ± 0.27 μm, which were coded as M1, M2, M3 and M4, respectively. In the second group, the metallic coatings were formulated from combinations of different percentages of M1 and M4 (Table 1). All the metallic coatings were mixed separately with solid coatings in nine color centers including blue, yellow, red, green, purple, cyan, orange, Greenish yellow and gray, which were uniformly distributed in CIE (1976) $L^*a^*b^*$ color space, with a ratio of 70:30, metallic: solid. Therefore, 63 (7 × 9) samples were prepared in total: each color center contained seven samples with different flake sizes which are given in Table 1.

It should be mentioned that the prepared samples had visual texture, which is defined as perceived non-uniformity of the color over the surface of a sample [14]. The use of aluminum flakes with different sizes led to different surface textures which created different chromaticity values, consequently. The metallic coatings were prepared to have high gloss value by applying proper thickness of clear coat for all the samples [15]. The gloss value of the prepared samples, which was measured by a Novo-Gloss-IQ goniophotometer, were almost the same and upper than 95 GU. Using a Gretag Macbeth Color-Eye 7000A spectrophotometer, which is an instrument with d/8° (diffuse/8°) geometry, the color coordinates of the samples were measured in a specular component included (SCI) mode. Since surface texture can diffuse light in all directions, using specular component excluded (SCE) mode may eliminate a part of the diffuse component of light instead of the specular component. So, SCI mode was chosen for measuring the color coordinates of the samples. The color differences between M1 and the other samples were computed for each color center. The color differences ranged from 1 to 13 CIELAB units, which referred to small, medium and large color differences. The color coordinates of the samples in the CIE (1976) $L^*a^*b^*$ color space under CIE standard illumination D65 and CIE 1964 standard observer (10°) are shown in Table 2.

2.2. Visual assessments

The visual assessments were carried out under semi-diffuse illumination conditions which were combination of unidirectional and diffuse illuminations to evaluate the total appearance. The semi-diffuse illumination conditions were constructed by 30 D65 simulator light sources, which had color rendering index higher than 85. The lamps were put on the roof in three rows with equal distances (10 lamps in each row), the distance between the roof and the setup of visual assessment was about 2 m. The samples were placed on a table with a middle gray color, which was set with a 45° angle to the horizon. The visual assessments were carried out at near zero degree from the sample normal and at 50–60 cm away from the sample surface. The size of samples was 10 cm × 10 cm corresponding to the CIE 1964 standard observer (10°). The perceived color differences were assessed between M1 and the other six samples for each color center. So, 54 sample pairs (6 pair for 9 color center) were assessed in total.

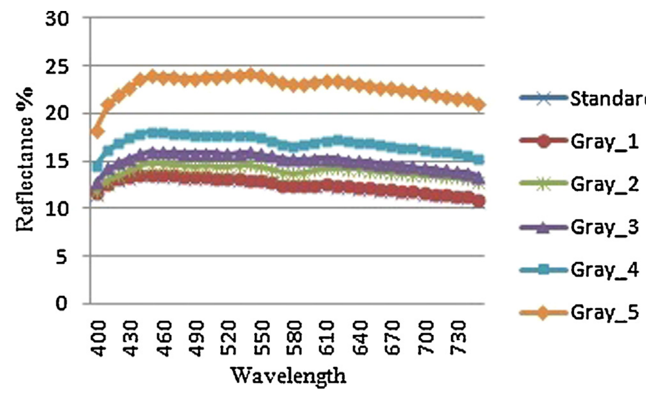

Fig. 1. Spectral reflectances of the gray scale samples.

2.3. Observers

Visual assessments were made by a total of 25 observers including 14 women and 11 men. The average age of the observers was 30 years. The observers were chosen from the institute for color science and technology and were almost aware of color sciences. All the observers passed the Ishihara test for color blindness and were found to have good color acuity. During the test, the observers wore cotton gloves to avoid thumb marks or damaging the surface of the samples.

2.4. Visual test method

The visual assessments were carried out using a gray scale method. Five gray samples (grades) and a standard, which were not textured, were prepared using gray solid base coat, with no metallic flake, in accordance with ISO A02 [16] for this purpose. The prepared gray scale was similar to the standard gray scale used in fastness testing for assessing color change in the textile industry. The spectral reflectances of the prepared gray scale are shown in Fig. 1.

The $CIEL^*a^*b^*$ values for each gray and the standard under illuminant D65 and CIE 1964 standard observer along with ΔL^* and ΔE *CIELAB* values, calculated between the standard and each gray, are given in Table 3.

As illustrated, the ratio of ΔL^* to ΔE values are almost equal to unity, which indicates that all differences are essentially lightness differences. It can be seen that the distances between the standard and each grade are based on the logarithmic perception of human vision.

Each observer was asked to report the visual assessments in terms of the grade number as perceptual difference. In addition, the observers were permitted to score decimal number by a step value of 0.25.

2.5. Conversion of gray scale to visual difference

Using a third-order polynomial equation, the raw data from the visual assessments of the sample pairs with gray scale were converted to corresponding color difference values. The coefficients of the best third-order polynomial equation which fitted ΔE^*_{ab} of the gray pairs over the gray numbers was shown in Eq. (1), where G is the gray number and ΔV is the corresponding color difference value.

$$\Delta V = 0.2050G^3 - 1.1664G^2 + 3.7886G - 2.3920 \quad (1)$$