Luster measurement of pearl by UV-Vis reflectance spectroscopy

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Abstract. Pearl is an organic gem with its unique color and luster. One of the factors determining the quality and price of pearl is the luster. The different luster of pearls could be related to the different phase structures such as aragonite, calcite and vaterite. Previously, a gloss meter has been developed to measure light specularly reflected at 45° to the surface normal. Six different visual criteria for measuring gloss have been determined. Luster, a type of gloss, was defined as the ratio of specularly reflected light and that diffusely reflected normal to the surface. In practice, luster may be interpreted as relative brightness of specularly and diffusely reflecting areas. Due to the roundness of pearl, we measured the luster of pearl samples by a portable UV-Vis spectrophotometer with an integrating sphere. The luster could be calculated from the difference of CIELAB lightness measured by SCI and SCE geometries.

1. Introduction

Pearl is an organic gemstone widely popular due to its unique color and luster difference from other gems. Pearls originate from bivalves in both freshwater and seawater. When a foreign object such as the grain of sand or encapsulated parasite is caught into the shell and causes irritations, the bivalve releases a substance to coat the foreign object [1]. Its chemical composition is mainly composed of calcium carbonate ($CaCO_3$) more than 80 %, conchiolin 10 % to 14 % and water 2 % to 4 %. The outer layer of pearl is called nacre. If the nacre layer is thick, the pearl is lustrous. This surface structure gives rise to interference and diffraction of light which leads to the phenomenon of iridescence that produces the luster of a pearl [2].

The qualities that determine the overall value of a natural or cultured pearl are size, shape, color, surface quality, nacre quality and luster. The different luster of pearls could be related to the different $CaCO_3$ phases in their structures, i.e. aragonite, calcite and vaterite [3]. Luster is one of the identifiable features of a pearl because it can be judged qualitatively by the naked eye.

In 1934, Hunter developed a gloss meter to measure light specularly reflected at 45°. He determined six different visual criteria for measuring gloss. Luster, a type of gloss, was defined as the ratio of specularly reflected light and diffusely reflected normal to the surface. In practice, luster may be interpreted as relative brightness of specularly and diffusely reflecting areas [4].

However, the luster measurement method is related to the flatness of the measurand. Due to the roundness of pearl, we measured the luster of pearl samples by a portable UV-Vis spectrophotometer with an integrating sphere. The spectra of UV-Vis spectrophotometer could be converted to color scales such as CIE L^*C^*h for color measurements of rice grain [5] and ADMI (American Dye Manufacturers' Institute) for color measurement of wastewater [6]. The luster was calculated from the difference of CIELAB lightness measured by specular included and specular excluded geometries.

2. Experiment

Two sets of pearl samples were prepared shown in figure 1. All of the samples were freshwater pearl. The first set, on the top row, consists of four samples that were PK-3, PK-9, PKC3 and PKC8. The sample sizes varied in diameter with irregular shapes. The second set, on the bottom row, consists of five samples that were A1, A5, A6, E3 and F1. The sample size was about 8 mm in diameter with a regular round shape.

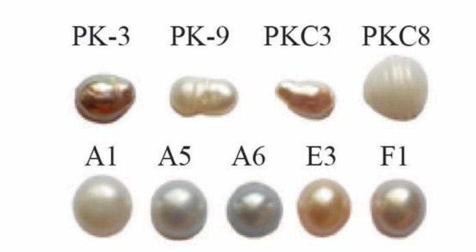

Figure 1. Freshwater pearl samples with different shapes, colors and luster.

We carried out UV-Vis reflectance spectroscopy using a portable spectrophotometer with an integrating sphere. The spectrometer was AvaSpec^{TM} fiber optic type based on the Czerny-Turner design with a 2048 pixel CCD detector array. The spectrum range was about 275 nm to 1100 nm. The spectrophotometer was initialized by saving dark and white using specularly included (SCI) mode. Each sample was placed into the sample holder of the integrating sphere for UV-Vis reflectance measurements to obtain nine SCI spectra. Then, the specular port was opened for the specularly excluded (SCE) mode of measurements to obtain another nine spectra.

The spectra were exported from the raw data to 360 nm to 830 nm with the wavelength steps of 5 nm for color calculation. The CIE *XYZ* (tristimulus) values can be calculated by [7]

$$X = k\sum_{\lambda} S(\lambda)R(\lambda)\bar{x}(\lambda)\Delta\lambda \tag{1}$$

$$Y = k\sum_{\lambda} S(\lambda)R(\lambda)\bar{y}(\lambda)\Delta\lambda \tag{2}$$

$$Z = k\sum_{\lambda} S(\lambda)R(\lambda)\bar{z}(\lambda)\Delta\lambda \tag{3}$$

where $S(\lambda)$ is the relative spectral power, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the color matching function, $R(\lambda)$ is the spectral reflectance of an object surface and k is a normalizing factor,

$$k = \frac{100}{\sum_{\lambda} S(\lambda)\bar{y}(\lambda)\Delta\lambda} \tag{4}$$

The CIE 1931 standard observer matching function (2°) and the spectral power distribution illuminant source of D65 were selected.

Then, the tristimulus values of X, Y and Z are converted to the CIE $L^*a^*b^*$ color space for both SCI and SCE. Each color indices can be interpreted separately. The L^* is the value of the lightness which ranged from 0 (black) to 100 (white). The a^* and b^* have no specific numerical limit. Positive a^* is red while negative is green, and positive b^* is yellow while negative is blue. The colors will deepen as the absolute values of a^* and b^* increase.

The color space is defined by

$$L^* = 116f(Y/Y_n) - 16 \tag{5}$$

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \tag{6}$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)] \quad (7)$$

where

$$f(X/X_n) = (X/X_n)^{1/3} \quad \text{if} \quad (X/X_n) > (24/116)^3 \quad (8)$$

$$f(X/X_n) = (841/108)(X/X_n) + 16/116 \quad \text{if} \quad (X/X_n) \leq (24/116)^3 \quad (9)$$

and

$$f(Y/Y_n) = (Y/Y_n)^{1/3} \quad \text{if} \quad (Y/Y_n) > (24/116)^3 \quad (10)$$

$$f(Y/Y_n) = (841/108)(Y/Y_n) + 16/116 \quad \text{if} \quad (Y/Y_n) \leq (24/116)^3 \quad (11)$$

and

$$f(Z/Z_n) = (Z/Z_n)^{1/3} \quad \text{if} \quad (Z/Z_n) > (24/116)^3 \quad (12)$$

$$f(Z/Z_n) = (841/108)(Z/Z_n) + 16/116 \quad \text{if} \quad (Z/Z_n) \leq (24/116)^3 \quad (13)$$

where X_n, Y_n, Z_n are the tristimulus values of a reference white object color stimulus.

For luster measurement, we calculated the difference lightness (ΔL^*) between SCI mode (L_i^*) and SCE mode (L_e^*) as

$$\Delta L^* = L_i^* - L_e^* \quad (14)$$

and difference color indices (Δa^* and Δb^*) between SCI mode (a_i^* and b_i^*) and SCE mode (a_e^* and b_e^*) as

$$\Delta a^* = a_i^* - a_e^* \quad (15)$$

$$\Delta b^* = b_i^* - b_e^* \quad (16)$$

3. Results and discussion

The UV-Vis reflectance spectra of the pearl samples measured by SCI and SCE mode are shown in figure 2 for the first set as the representation. The spectra measured by SCE mode were found to lower reflectance comparing to SCI mode in all samples. The spectra line shape were similar for each sample measured with the different modes. Different line shapes of the spectra are due to the different colors of pearl samples. The reflectance of PKC3 and PKC8 measured by SCI mode was higher than 100 % at the wavelength of 410 nm and 520 nm. These could be influent by the high specular reflectance of the samples.

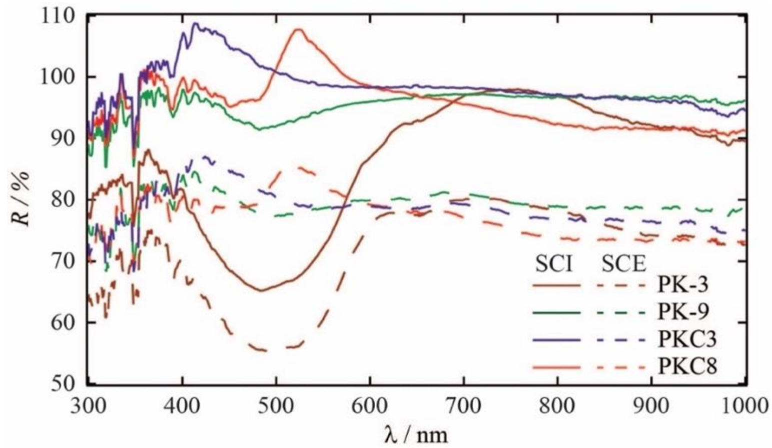

Figure 2. UV-Vis reflectance spectra of the represented pearl samples.

The pearl samples with different luster were inspected qualitatively by naked eyes. For the first set of samples, the luster could be classified from high to low as PK-3, PKC3, PK-9 and PKC8 respectively. Table 1 shows the color indices of L_i^*, L_e^*, a_i^*, a_e^*, b_i^*, b_e^*, ΔL^*, Δa^* and Δb^*. The values of L_i^* were significantly higher than L_e^* in all samples shown as ΔL^*, correspond to the UV-Vis reflectance spectra while the values of a_i^* and a_e^* were not significant difference shown as Δa^* as well as the values of b_i^*

and b_e^* shown as Δb^*. To classify the luster by the ΔL^* results, we found the luster from high to low as PKC3, PKC8, PK-9 and PK-3 respectively. The luster order of the results did not correspond to the visual inspection. Hence, the shape and size of the samples might influent the luster values.

Table 1. The values of color indices measured by SCI and SCE modes and the difference color indices of the first set of pearl samples.

Sample	L_i^*	L_e^*	a_i^*	a_e^*	b_i^*	b_e^*	ΔL^*	Δa^*	Δb^*
PK-3	92.37	85.71	11.85	11.59	5.35	4.86	6.65	0.26	0.49
PK-9	98.92	91.41	1.59	1.95	-0.86	-1.30	7.51	-0.36	0.45
PKC3	102.32	94.52	-5.47	-4.84	2.71	2.56	7.80	-0.64	0.15
PKC8	99.91	92.35	1.29	1.70	-4.57	-4.78	7.57	-0.42	0.21

Therefore, we measured the second set of pearl samples. The lusters of the samples were classified qualitatively by naked-eye inspection. We found that the luster from high to low was A6, A5, F1, E3 and A1 respectively. The measurement results of L_i^*, L_e^*, a_i^*, a_e^*, b_i^*, b_e^*, ΔL^*, Δa^* and Δb^* are tabulated in table 2. The values of L_i^* and L_e^* were higher than 100 for A1, E3 and F1. These results indicate high reflectance of the samples compared to the reference standard. To classify the luster by the ΔL^* results, we found the luster from high to low as A6, A5, F1, E3 and A1 respectively. The luster order of the results corresponded to the visual inspection. Hence, the size and shape of the pearl could influence the luster value.

Table 2. The values of color indices measured by SCI and SCE modes and the difference color indices of the second set of pearl samples.

Sample	L_i^*	L_e^*	a_i^*	a_e^*	b_i^*	b_e^*	ΔL^*	Δa^*	Δb^*
A1	116.30	110.05	-2.42	1.86	-15.28	-12.24	6.25	-4.29	-3.04
A5	104.95	97.28	1.26	1.83	-13.86	-13.29	7.67	-0.57	-0.57
A6	102.79	93.83	-1.41	-0.62	-14.61	-13.17	8.96	-0.79	-1.44
E3	112.80	106.08	2.10	5.59	-11.99	-9.47	6.73	-3.49	-2.52
F1	113.43	106.62	1.00	4.71	-13.57	-11.05	6.81	-3.71	-2.53

4. Conclusion

The UV-Vis reflectance spectroscopy by a portable spectrophotometer with an integrating sphere was used for luster measurement of pearl samples to calculate the difference of CIELAB lightness for the spectra measured by SCI and SCE geometries. The measurement results have well corresponded to the luster of pearl samples. Therefore, this is a promising method for luster measurement of pearl.

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