

Color recipe prediction for facial episthesis materials

P. Berssenbrügge*, C. Runte*, M. Dekiff*, C. Denz**, D. Dirksen*

*Poliklinik für Prothetische Zahnmedizin und Biomaterialien, Universitätsklinikum Münster

**Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster

<mailto:berssenbruegge@uni-muenster.de>

We present a color recipe prediction for facial episthesis materials. It allows to compute the mixing ratios of main skin color silicone colorants in order to obtain a requested color. The technique is based upon the radiative transfer model by Kubelka and Munk. The required remission spectra of color specimens are acquired with our goniometric color measuring system.

1 Introduction

The computer aided design of epistheses, i. e. artificial substitutes for body parts (example see Fig. 1), involves the construction of a suitable shape and the reproduction of the colors of the replaced or surrounding skin surface. The latter is a crucial point especially for facial epistheses.

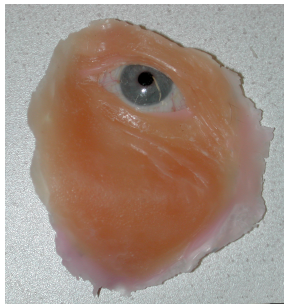


Fig. 1 Orbital episthesis.

Color reproduction is based on a precise measurement of the color defining remission spectrum. Furthermore, it requires a method of color recipe prediction, i. e. the calculation of concentrations of given colorants, necessary to reproduce a certain color. An adequate model describing the radiative transfer within translucent materials is the two-stream approximation given by Kubelka and Munk [1]. As this theory excludes a refractive index change at the surface, an additional surface correction is applied in order to convert the measured overall remission of a color specimen into the internal remission caused only by absorption and scattering within the medium. On the basis of color specimens of episthesis material mounted on white and black coated substrates, the coefficients of absorption and scattering of the involved colorants are determined. Examples of color recipe prediction based on these data are presented.

2 Radiative transfer of a translucent material on a substrate

The spectral reflectance of a specimen of translucent material on a substrate (Fig. 2) can be de-

scribed as a combination of three effects of radiative transfer [2]: the internal diffuse reflectance according to Kubelka and Munk, the reflectance of the translucent layer in interaction with the substrate and the surface correction according to Fresnel and Saunderson. The surface effect is caused by the change of refractive index between the colorant and the surrounding air.

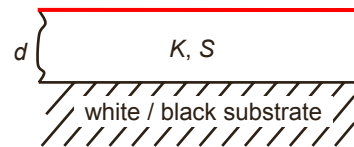


Fig. 2 Translucent episthesis material of thickness d , with absorption K und scattering S on substrate.

3 Internal diffuse reflectance in the model of Kubelka and Munk

The radiative transfer within the colorant (Fig. 3) is regarded as consisting of two diffuse streams in opposite directions and is subject to absorption $K(\lambda)$ and scattering $S(\lambda)$ following this system of differential equations for each wavelength λ :

$$\begin{aligned} \frac{dI_+}{dx} &= -(K + S)I_+ + SI_- \\ -\frac{dI_-}{dx} &= +SI_+ - (K + S)I_- \end{aligned} \quad (1)$$

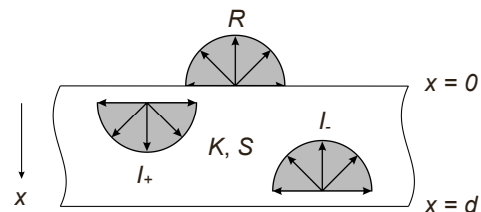


Fig. 3 Two diffuse streams in a coplanar layer.

This system provides a closed-form solution for the remission R of a coplanar layer of thickness d .

4 Goniometric color measuring system

The system depicted in Fig. 4 allows an automated measurement of spectral reflectances at different observation angles with an angular resolution of 4° [3]. It is calibrated with a white reflectance standard made of BaSO_4 . After a warm-up period of 0.5 h and a subsequent calibration, the measured $L^*a^*b^*$ -values remain stable with $\Delta E < 1$ for 1 h.

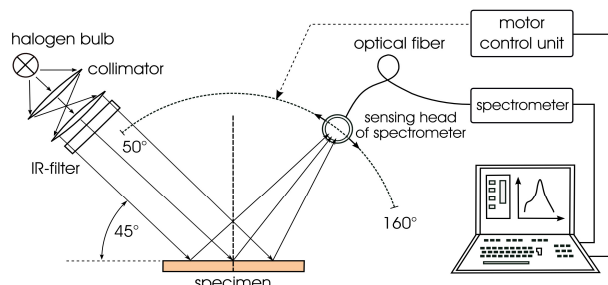


Fig. 4 Setup of the goniometric measuring system.

5 The procedure of color recipe prediction

Here examples of color prediction are presented for two-component-mixtures of three main skin color silicones and one transparent silicone. These colorants (Bredent, Senden, Germany) are the basic materials for facial episthesis manufacturing.

In a first step, the spectral reflectances of the pure colorants and mixtures of them with known ratios applied on a black and white substrate are measured. Additionally, the spectral reflectances of the substrates alone and the layer thicknesses of all specimens are measured. These data are used to characterize the colorants. This means, the spectra of absorption and scattering coefficients of the pure colorants are determined by an iterative matching of a theoretical reflectance to the measured ones with the Levenberg-Marquardt-algorithm. Then, a new pass of the matching is performed. This time, the mixing ratios are the unknowns. The result is a color recipe which is then realized as a real mixture, compared to the requested color and corrected if necessary.

6 K and S spectra of the pure colorants

Fig. 5 shows specimens of two skin color silicones named "city" and "country". They are applied as a translucent layer on black and white substrate. Their K and S spectra, essential in the model of Kubelka and Munk are shown in Fig. 6. Absorption and scattering characteristics are consistent with the appearance regarding color and transparency.



Fig. 5 Specimens of pure "city" and "country" silicone.

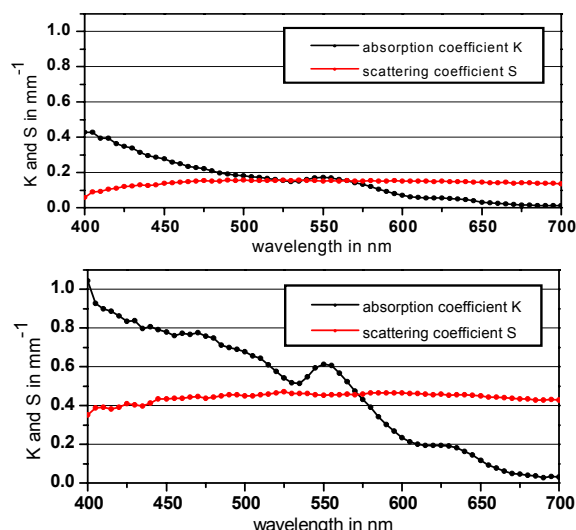


Fig. 6 K and S of "city" (top) and "country" (bottom).

7 Result of recipe prediction for two colorants

For a 50 : 50 mixture of "city" and "country", the recalculated recipe predicts 55 : 45. The theoretical remission calculated from this ratio and the K and S constants of Fig. 6 is compared to the measured one in Fig. 7. The color distance between these two spectra is $\Delta E = 0.81$.

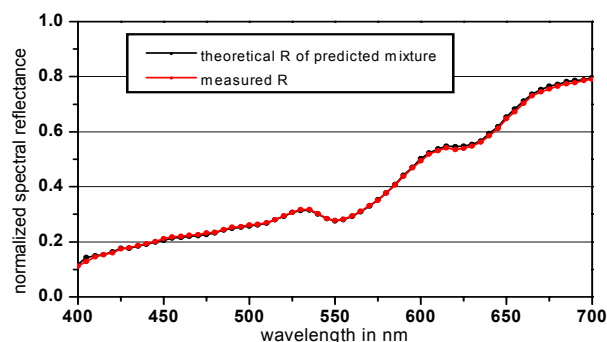


Fig. 7 Predicted and measured spectral reflectance.

8 Conclusions

The Kubelka-Munk theory provides a suitable framework for radiative transfer in layer-on-substrate-systems of episthesis materials. Our color measuring system delivers sufficiently accurate and reliable data for color recipe prediction. The two-component recipe prediction provides low- ΔE -results even with very similar colorants.

References

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- [3] R. W. G. Hunt: *Measuring Color*, (Fountain Press 1998)

Financial support by the Deutsche Krebshilfe (German Cancer Aid) is gratefully acknowledged.