UDC 621.315.5; 621.318.1

SPECTRO-POLARIZED IMITATION OF VEGETATION

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Submitted 23 February 2009

Methods for creation of composite materials on the basis of vegetation are presented. Application of dry milled leaf of laurel as a basic component for the imitation of vegetative background is offered. Investigation of optical properties of the synthesized materials was carried out in range of wavelengths of 440–1040 nm. It was established that changing a state of the filler (milled leaf) and a technology of silicone based composite formation leads variation of the material optical properties in wide range of polarization and spectral brightness coefficient that makes possible imitation of different kind of vegetation. The examples of the possible use of the developed materials are discussed.

Keywords: spectral brightness coefficient, degree of polarization, composite material.

Introduction

Now considerable progress in the development of methods for remote sensing as a way of investigation of natural resources of the Earth is observed. The measurement, the transformation and the analysis of physical parameters of light radiated and reflected by objects, makes a basis of remote optical sensing methods. Measured parameters in these investigations are spatial, time and angular dependences of power, spectral and polarizing characteristics of radiation of the Earth and objects on its surface [1]. Measurements of the optical parameters are progressed together with development of hardware and software for processing of video data that allows receiving more exact information about artificial and natural objects, to separate out its image data and parameters.

Measurement of polarization of the optical radiation adds data on properties of investigated objects but considerable part of this information essentially can't be received from traditional measurements of intensity [2]. For example, the vegetation is easy recognized by presence of the characteristic biotic minimum in a range of 635–680 nm, caused by absorption of radiation by chlorophyll. The chlorophyll reflection-adsorption dependence is characterized by low reflection coefficient till wavelength of 680 nm then its growth is observed [3].

From the other side for some special application the decrease the visibility of land objects of the different function becomes now a very actual problem. The human eye is a highly effective receiver of the visual information. Development of means and systems for optical remote sensing, application of different optical devices allow increasing the land object detection distance. The problem of decrease of its visibility in an optical range can be solved by application of special materials that demonstrate spectral and polarizing characteristics similar to corresponding characteristics of a natural environment (green plantings, soils etc.) [4].

One of the perspective directions for the fabrication of materials with required optical properties is formation of composite (heterogeneous) structures that allows to control macroscopic characteristics of a material not only by change of the concentration of injected filling compound, but also by variation of the particles size [5].

The objective of the present work is development of the composite material simulating natural vegetation in optical range, and investigation of its spectral and polarizing characteristics.

Experimental

For the creation of the vegetation simulator we propose a composite material with components that are similar to natural vegetation. Application of live leaves as elements of long-term artificial coverings is impossible because of their fast withering and accordingly changes of their optical characteristics. Another technological problem of fixing of live leaves in binder was observed. The most accessible way for composite synthesis by filling quality and visually-optical characteristics similar to live leaf was based on using of the dry leaf of laurels (sample *1*).

The use of entire dry leaf for the creation of the big sizes materials is a labor-consuming and pure technological process. So the pressing method allowing fixing milled laurels has been offered in order to create a sheet material for investigations (sample *2*). Additionally a composite material sample based on the dry milled laurels fixed in silicone (sample *3*) has been made. Components of a synthesized material were carefully mixed up for the formation of homogeneous mass that was unrolled in sheets and was drying at temperature +20°C. Resulted samples of materials were about 5 mm thick.

For study of the created material samples in visible and near infra-red (NIR) ranges (wavelengths 440–1040 nm) we used a goniometric installation and a spectropolarimeter Gemma MS-09 with the polarizing attachment, allowing registration a spectral radiance (SR) of samples at various positions of an axis of the polarizer in dimension of W/cm^2·μm·sr[6].

A quartz-halogen bulb GKM-250 having maximum SR at wavelength about 1.0 μm (light temperature ≈3000°K) was used as a light source. The angle of incidence of a collimated light beam on investigated sample (γ) was 40, 45 and 50° (Fig. 1). It was used three positions of axis polarizer relative to the vertical surface: 0, 45 and 90°. Observation angles (β) have been chosen at the fixed positions: 0, 10, 20, 30, 40, 50, 60 and 70°. Observation and incidence angles were counted from a normal to a plane of investigated sample.

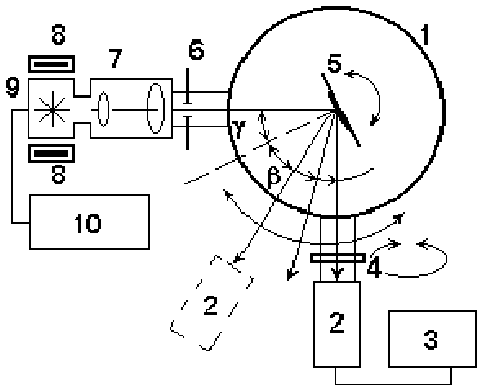


Fig. 1. Block diagram of goniometric measuring installation: *1* — goniometer G-5; *2* — MS-09; *3* — the IBM-computer; *4* — polarizer; *5* — investigated sample; *6* — diaphragm; *7* — collimator; *8* — cooling system; *9* — lighting lamp KGM-250; *10* — power unit SNP-40

Energy supply of a lighting lamp was stabilized and controlled that ensures the brightness of an illumination source didn't change in the course of measurements. Spectropolarimeter registers the reflected from sample SR in a range of wavelength of 440–1040 nm. Obtained data were used for calculation of spectral brightness coefficient (SBC) and degree of polarization values. For each angle of observation the spectrum of reflection averaged on three next channels have been received.

Analysis of the spectrum of reflection and calculation of SBC for the investigated samples was made at fixed normal conditions in comparison to reflection spectrum of the test sample that was made on the base of milky glass MS-20 and demonstrated high factor of reflection of an order of 0.95 in the wavelengths range of 440–1040 nm and uniform dispersion index. The spectral brightness coefficient was calculated as a relation of SR of an investigate material to SR of sample with uniform dispersion index.

Conditions of light reflection from sample surface were studied using Stock's parameters calculation. For that the spectral characteristics of the same investigated material were registered at three various orientations of the polarizing filter (0, 45 and 90°) relative to a vertical following primary parameters: I_0, I_{45}, I_{90} — SR for corresponding orientations of the polarizer were received.

Calculations of Stokes parameters (*L, Q, U, V*=0) [2] were carried out using the following mathematical expressions:

$$L = I_0 + I_{90}, \quad (1)$$

$$Q = I_{90} - I_0, \quad (2)$$

$$U = I_0 + I_{90} - 2I_{45}\,. \qquad (3)$$

On the basis of Stokes parameters a degree of polarization (P) for investigated samples of materials has been calculated:

$$P = \sqrt{Q^2 + U^2} \Big/ L\,. \qquad (4)$$

A contrast on SBC and degree of polarization values for investigated samples were calculated for the analysis of spectral dependences of radiation:

$$K_L = \frac{L_1 - L_2}{L_1 + L_2}, \quad K_P = \frac{P_1 - P_2}{P_1 + P_2}, \qquad (5)$$

here L_1 and L_2 — samples SBC, normalized by its general maximum, P_1 and P_2 — degree of polarization of samples radiation. The index 1 is assigned to the sample characteristic with known contrast, index 2 — to a background (single live leaf).

Results and discussion

A surface of material samples was investigated with the help of a metallographic microscope "Metam R-1". It is established, that on the surface of the sample, which was made by a method of compressing the particles of milled laurels with size from 9 to 104 microns, there is a uniform distribution of elements on all surface of the sample. Placing of milled laurels in silicone leads to creation of heterogeneity on a surface of a material with the sizes from 17 to 52 μm. A dominant heterogeneity size was in the range of 35–40 μm (Fig. 2, 3).

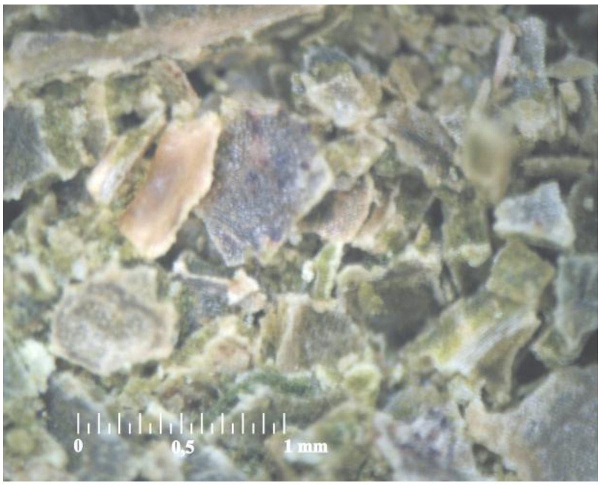


Fig. 2. Laurel milled pressed

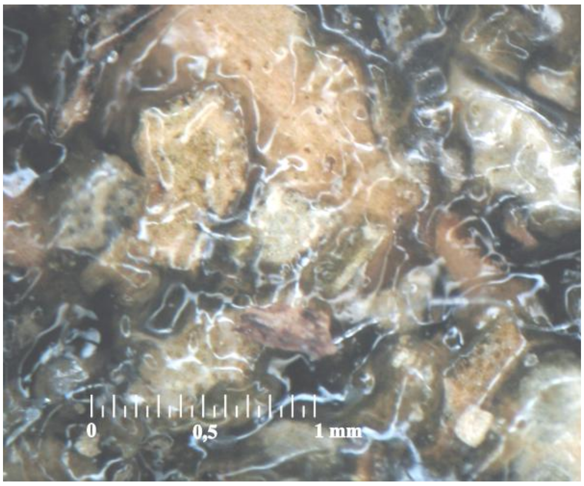


Fig. 3. Laurel milled in silicone

On the basis of the analysis of experimental data it is established, that in a range of 440–640 nm the SBC characteristic of entire dry leaf does not go beyond value of 0.6 (Fig. 4). Increase of SBC in green area of the spectrum (550 nm) and increased slope of the characteristic to about 660 nm is observed. Then SBC increases and leaves on a plateau in a range of 730–920 nm beyond the 0.9. The uniform increase in SBC value is observed at change of observation angle from 0 to 70°. It is established, that changing of observation angle 40, 45 and 50° increases SBC on 0.1–0.15.

It is shown, that the maximum value of polarization degree of entire dry leaf is observed in ranges of 460–470 and 650–660 nm. In a range of 720–780 nm the polarization degree is much lower and falls down to value 0.3 (Fig. 5). A polarization degree value increases with increase of observation angle. In IR areas with wavelength higher than λ>800 nm the value of polarization degree cannot be measured correctly because of limitation of an applied polarizer spectral working range.

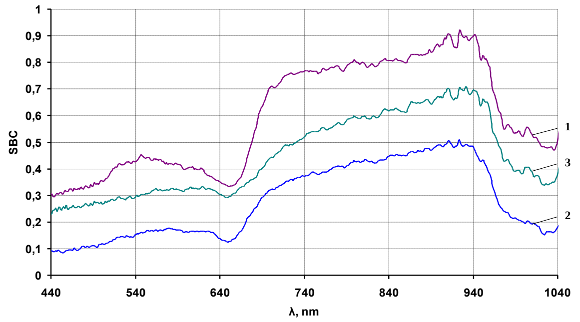


Fig. 4 Wavelength dependences of SBC of the radiation reflected from *1* — dry leaf; *2* — dry milled pressed leaf; *3* — dry milled leaf fixed in silicone at γ=45°, β=70°

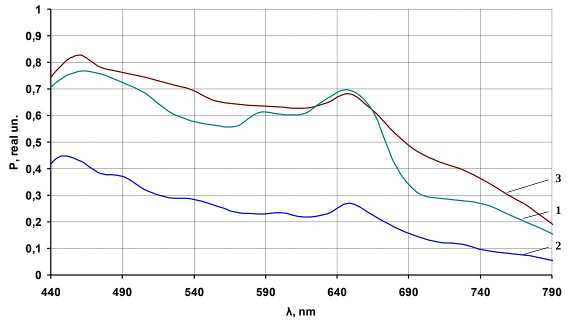


Fig. 5 Wavelength dependences of degrees of polarization of the radiation reflected from *1* — dry leaf; *2* — dry milled pressed leaf; *3* — dry milled leaf fixed in silicone at γ=45°, β=70°

The analysis of optical properties of the pressed laurel leaf has shown that SBC of the given material is less than that of entire dry leaf. In a range of 440–640 nm the SBC characteristic does not go beyond value 0.2. Increase in reflection near to 550 nm (green area of a spectrum) and slope of the characteristic near to 660 nm is observed. Then SBC increases in regular intervals and does not exceed value 0.75 in a range of 730–920 nm (Fig. 4).

It is established, that value SBC practically does not depend from the observation angle. It is caused by uniform distribution of the different sizes of elements of milled leaf and by presence of heterogeneities on a surface of a material that supports diffuse dispersion of the radiation reflected from them. With increase of the incidence angle from 40 to 50° an insignificant reduction of SBC on 0.1 is observed.

Using of the pressed laurel leaf results in considerable reduction of polarization degree (Fig. 5). At small observation angles (0, 10 and 20°) it reaches values 0.15. Low value is caused by diffuse dispersion of falling light by the sample surface. The maximum polarization degree is observed at observation angle β =70° and reaches 0.45. Polarization degree has the maximum value in a range of 460–470 and 650–660 nm, and then the characteristic goes on recession. Polarization degree increases with the increase of observation angle.

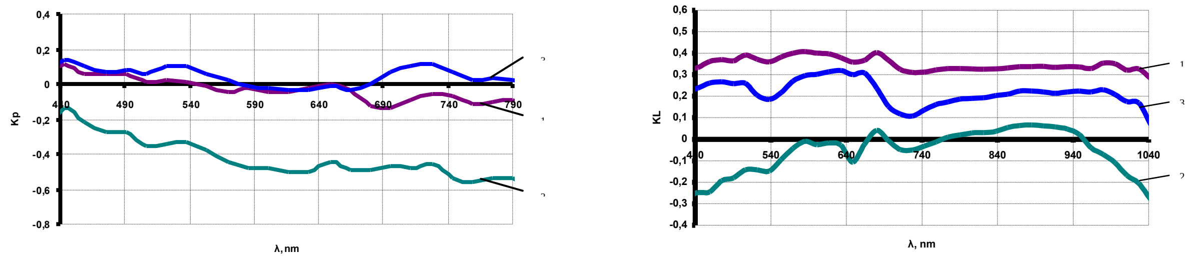
Using of the silicone as a binding substance has led to increase of SBC, degree of polarization and disorder of SBC parameters for various observation angles. The heterogeneities on material surface have been smoothed that has led to reduction of diffuse dispersion of the reflected radiation. In a range of 440–640 nm characteristics SBC is uniform and does not exceed value 0.35, recession of the characteristic near to 660 nm is observed. Further SBC increases and in a range of 730–920 nm reaches value 0.8 (Fig. 4, 5).

Increased SBC is observed at change of observation angle from 0 to 70°, that approaches the behavior SBC of the sample to the characteristic of dry leaf. It is established, that at change of the angle of incidence at 40, 45 and 50° insignificant increase of SBC at value less than 0.1 is observed.

The use of silicone as a binding component has led also to increase in polarization degree to value 0.82. Degree of polarization has the maximum value in a range of 460–470 and 650–660 nm, and then the characteristic goes on recession (Fig. 4, 5). Polarization degree value increases for a composite material at increase of observation angle.

The results of the analysis of contrasts SBC and degrees of polarization are presented in Fig. 6. Contrast of polarization degree of samples *1* and *2* lays within 0.2 on the module for all wavelengths, but the contrast of the sample *3* reaches values 0.55. Negative contrast mean, that for the given conditions the sample *2* polarizes less, than a background.

Contrast of brightness of single dry leaf in a range of 440–690 nm reaches values 0.4, then the characteristic decreases to 0.33. K_L of the dry milled leaf fixed in silicone, in a range of 440–490 nm lays within 0.2–0.3, then the characteristic decreases to limits 0.1–0.2. The minimum value of brightness contrast is observed for the sample *2*. Its level is found within 0.1 on the module, except for separate ranges where the characteristic reaches values –0.25.



a *b*

Fig. 6. Contrast of polarization degree (*a*) and contrast of brightness (*b*) of the radiation reflected from samples (*1* — dry leaf; *2* — the dry milled pressed leaf; *3* — the dry milled leaf fixed in silicone) and single live leaf at γ=45°, β=70°

Conclusion

Thus, developed technological process for fabrication of composite materials allows formation of materials with the polarizing characteristic and SBC that can be adapted to several kinds of natural objects. Spectral characteristics of materials are defined by interaction of a light wave with a surface of the synthesized material. Therefore the sizes of elements and the surface shape are of the great importance.

As the investigations have shown, it is expedient to apply dry leaf for the imitation of live vegetation since its optical characteristics are similar to characteristics of live leaf. The reflection increase in green area of a spectrum and characteristic recession of SBC near to 660 nm corresponding to a range of chlorophyll absorption that is connected with preservation of the given pigment in the course of leaf drying is observed. Contrast of polarization degree of dry leaf against live one is less than value 0.1 on the module, and the SBC contrast does not exceed value 0.4 for all wavelengths.

The method of pressing of dry leaf leads to reduction of SBC and polarization degree that is connected with presence of the heterogeneities on the material surface and diffuse dispersion of the reflected wave. Value K_p reaches 0.55, therefore the given material has low efficiency for visibility decrease of the samples against vegetation.

The analysis of experimental data testifies to change of a structure of blankets in the course of fixing of dry leaf in silicone therefore there is a smoothing heterogeneity on a material surface. The composite material consisting of a dry laurel leaf, fixed in silicone, at the expense of preservation in the structure of such pigment as chlorophyll under the spectral and polarizing characteristics is similar to vegetation. Contrast of polarization reaches value 0.15; contrast of brightness does not exceed value 0.32 for all wavelengths. The given material can widely be used for vegetation imitation.

The carried out investigations have the practical importance for working out of materials with lowered visibility in optical range.

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