

Встановлені закономірності зміни світлотинеоброблених та полірованих зразків з різних типів Покостівського гранодіориту в залежності від частки білих мінералів. Створена класифікація необроблених зразків з різних типів Покостівського гранодіориту за відтінками світлоти (за компонентою L, системи Lab) на основі сегментації зображення каменю на об'єкти і фон

Ключові слова: світлота каменю, Покостівський гранодіорит, забарвлення каменю, кольоровий тон каменю, цифрова обробка зображень

Установлены закономерности изменения светлоты необработанных и полированных образцов из различных типов Покостовского гранодиорита по цветовому тону в зависимости от доли белых минералов. Создана классификация необработанных образцов из различных типов Покостовского гранодиорита по оттенкам светлоты (по компоненте L, системы Lab) на основе сегментации изображения камня на объекты и фон

Ключевые слова: светлота камня, Покостовский гранодиорит, окраска камня, цветной тон камня, цифровая обработка изображений

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DEFINITION OF HUE OF DIFFERENT TYPES OF POKOSTIVSKIY GRANODIORITE USING DIGITAL IMAGE PROCESSING

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1. Introduction

In natural stone facing of buildings, there may be differences in the hue of different tiles caused by the mineralogical and chemical composition of the stone. Change in the natural stone color can be observed not only within a single deposit, but even within one site of a quarry. This problem occurs when manufacturing a large batch of natural-stone facing products. A characteristic feature of Pokostivskiy granodiorite (Grey Ukraine) is the change in lightness at a constant stone texture, perceived by the human visual analyzer. Thus, in natural stone facing of buildings, particularly of a large area, a problem is to select solid tiles [1].

Significant problems of selecting natural stone arise in the restoration and reconstruction of monuments and architectural objects made of natural stone. The reason is that the majority of the fields either have ceased to exist or other horizons of natural stone, decorative figures of which differ considerably are developed. It should also be noted that during prolonged use of natural-stone products, the machined stone surface gradually loses original aesthetic characteristics under the influence of an aggressive environment [2, 3].

2. Literature review and the problem statement

Currently, aesthetic indicators [4] are determined using the organoleptic method, which is subjective. But the present requires more objective methods for determining the decorative quality indicators of stone products. Standard colorimetric parameters – brightness, basic hue saturation, basic (dominant) hue wavelength can be determined in a quantitative form by information and computer technologies. The method that eliminates the subjective determination of decorative properties of rocks has been proposed in [5].

The changes in the microtexture of rock-forming minerals in natural stone grinding-polishing have been examined in [6, 7] using microscopy and spectral analysis of the mineral microtexture formation. Also, processes of abrasive machining have been experimentally investigated in [8]. The change in gloss depending on the stone surface roughness has been studied in [9], but high-strength natural stones have not been studied.

The effect of high temperatures on the change in the stone properties using digital image processing has been investigated in [10]. It has been found that the stone gets lighter with increasing temperature. Black-and-white digital image processing [11] has been used to identify light areas

on the natural stone surface in the study of the weathering influence and the effect of salts on stone. According to [12], stone roughness during polishing can affect the surface color. The work has studied not only the effect of polishing, but also the influence of acid environment on limestone and marble, which to some extent increases the stone surface roughness, but these changes are nonuniform. However, unlike mechanical polishing, the stone surface color after exposure to acidic environment depends not only on the surface roughness, but on the mineral particles that make up the rock.

Digital image processing methods based on the in vitro measurement of surface brightness and contamination of the stone, which was subjected to pollution in an urban environment have been described in [13, 14]. Over time this method has been improved, allowing to measure the color coordinates [15, 16], and the calibration procedure has been established [17].

The method of natural stone hue management using surface machining has been developed in previous studies [1, 18]. The stone hue management needs information about the color indices of raw decorative stone, which allows determining the stone processing technology at once according to the method.

The literature review shows that previous studies deal with the study of stone microtexture features [5, 6, 19], the effects of an aggressive environment [2, 3], the development of methods of determining color coordinates [11–17]. However, little attention has been paid to the study of the color characteristics of deposits of decorative stone within the same brand.

3. Research goal and objectives

The goal is to study the structural features of the types of Pokostivskiy granodiorite of different hues.

To achieve this goal, the following tasks were solved:

- to determine the patterns of lightness change of rough and polished samples of the types of Pokostivskiy granodiorite of different hues depending on the share of white minerals;
- to develop a method to identify the types of Pokostivskiy granodiorite of different hues using digital image processing;
- to make a generalized description of the types of Pokostivskiy granodiorite of different hues.

4. Materials and methods of study of grinding-polishing effects on gloss and lightness

4.1. Materials and equipment used in the experiment

The study was performed using stone samples of the types of Pokostivskiy granodiorite of different hues. A surface grinding machine with the specifications listed in Table 1 was used for machining.

Table 2 shows the numbers and grain size of the fickerts that were used as a diamond tool. It also shows the number of passes by those numbers. Such a scheme of use of the diamond tool provides a high quality and gloss of the stone surface. The gloss of Pokostivskiy granodiorite corresponds to the second category in terms of reflectivity and is provided by such a textured finish.

Table 1

Surface grinding machine specifications

Specifications	Value
Water consumption	30 l/min
Working head rotational speed	1.460 rpm
Working head lifting speed	1.98 m/min
Carriage speed	3.96 m/min

Table 2

Diamond tool specifications

Number of passes	Number of tool	Grain size, μm
calibration	№ 00 (diamond)	710/600
1	№ 24	500/400
1	№ 240	200/160
4	№ 400	80/63
2	№ 600	60/40
2	№ 800	40/28
2	№ 1200	28/20
2	№ 1500	20/14
2	№ 2000	10/7
2	№ 3000	5/3
1	Polishing	1/0

Research of structural features was conducted using the GAOSUO digital microscope. Scanning of polished surfaces of stone samples was carried out by the Skypix TSN 415 scanner.

4.2. Method of determining the types of Pokostivskiy granodiorite of different hues

The analysis of the surface appearance needs forming a digital image of the facing stone surface and its processing by means of modern computer technologies.

An example of determining the LAB color coordinates in the Mdistones program is shown in Fig. 1.

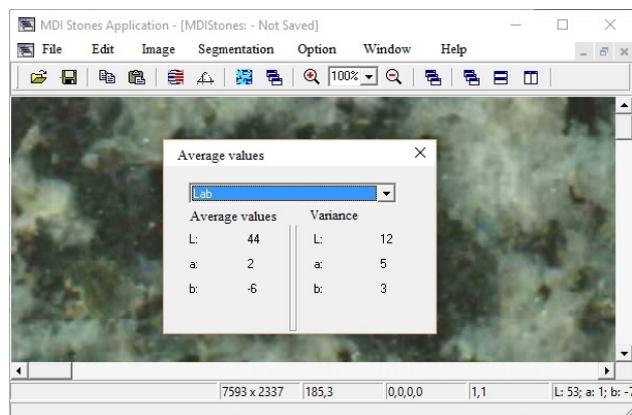


Fig. 1. Sample surface image processing in the Mdistones program

The procedure is as follows:

- machining of plates by diamond fickerts on surface grinding machine;
- drying of samples and scanning of the machined surface;
- processing of the resulting image in the Mdistones program;

- determination of the average lightness L in the LAB system for each of the images of the polished sample surface (Fig. 1);

- color correction, namely saturation increase (+255) using color processing functions in the Mdistones program;
- determination of the average parameters of the color coordinates A and B in the LAB system for each of the images of the polished sample surface.

The significance of the components A and B is observed when it exceeds ± 5 . At lower rates, they have almost no influence on the hue.

The hues of Pokostivskiy granodiorite are determined by the following factors:

- A=[+5; +120] – red hue;
- A=[-5; -120] – green hue;
- B=[+5; +120] – yellow hue;
- B=[-5; -120] – blue hue.

Since the values A and B are insignificant, the hue is determined by the coordinate with a greater module. For example, the estimated average parameters of the stone sample surface: L=30; A=-10; B=5 show that the module of the component A is greater than that of the component B. So, the hue is determined by this coordinate. In this case, there will be green hue:

- determination of the type of Pokostivskiy granodiorite according to the hue classification;
- splitting of polished samples of Pokostivskiy granodiorite of different hues, according to the classification, into two parts;
- obtaining a macroscopic image of the split sample surface using a digital microscope;
- determination of the average lightness L, and color coordinates of A and B in the LAB system for each of the images of the split sample surface (Fig. 2);

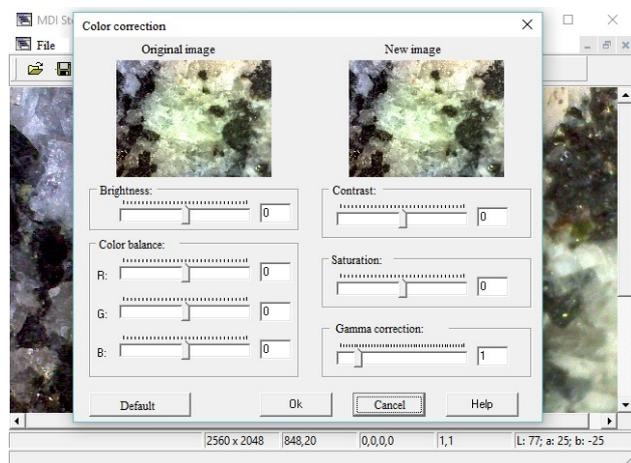


Fig. 2. Color processing in the Mdistones program

- image conversion to black-and-white;
- image segmentation into objects and background (Fig. 3). In this case, objects are regions of light-colored stone minerals, the background is the region of dark-colored minerals. The color segmentation method is used for image segmentation;
- determination of the total area of objects on the image and relation to the area of the entire image. This relation is a generalized indicator that characterizes the number of dark- and light-colored minerals;

- analysis and synthesis of data to create a method for determining the hue of rough samples of Pokostivskiy granodiorite.

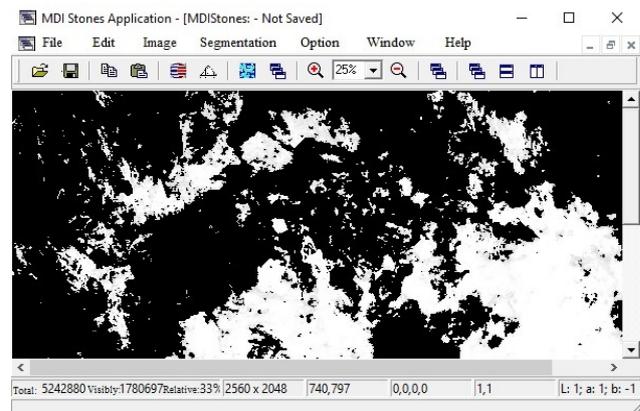


Fig. 3. Image segmentation into objects and background

5. Research of structural features of the types of Pokostivskiy granodiorite of different hues

A stone structure is considered as structure, which is caused by shape, size and quantitative ratio of minerals that make up the rock. As Pokostivskiy granodiorite is a monochrome type of stone, the lightness value will depend on the content of dark- or light-colored minerals. Description of structural features of the types of Pokostivskiy granodiorite of different lightness is shown in Fig. 4.

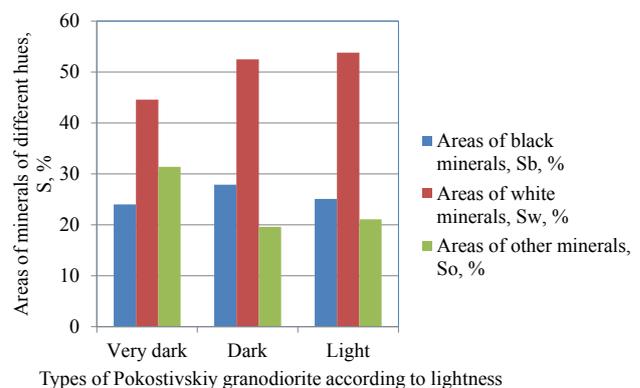


Fig. 4. Description of structural features of rough types of Pokostivskiy granodiorite of different lightness

Fig. 4 shows that the types of Pokostivskiy granodiorite of different lightness are characterized by different values of the areas of dark- and light-colored minerals shown in Table 3.

Also, stone surface lightness increases with the increase in the areas of light-colored minerals. The surface of split rough samples of Pokostivskiy granodiorite was investigated using a digital microscope, resulting in the graph of dependence of lightness changes in rough stone on the share of white minerals (Fig. 5).

Depending on the area of light-colored minerals, the lightness L for Pokostivskiy granodiorite is described by the 3rd order polynomial relationship:

$$L = -901,06 \left(\frac{S_w}{S_b + S_w} \right)^3 + 1769,7 \left(\frac{S_w}{S_b + S_w} \right)^2 - 1116,3 \frac{S_w}{S_b + S_w} + 284,01, \quad (1)$$

where L – lightness, %; S_w – areas of white minerals, %; S_b – areas of black minerals, %.

It is known that polishing of decorative stone improves decorative properties, namely emphasizes its texture and structure. Stone lightness and other properties also change. Therefore, structural properties of not only rough, but also polished stone were investigated.

Table 3

Description of rough samples of the types of Pokostivskiy granodiorite of different lightness

Type of stone according to lightness	Areas of black minerals, S _b , %	Areas of white minerals, S _w , %	Areas of other minerals S _o , %	Average lightness L _{avg} , %
Very dark	24	44.6	31.4	58.8
Dark	27.9	52.5	19.6	59
Light	25.1	53.8	21.1	59.5

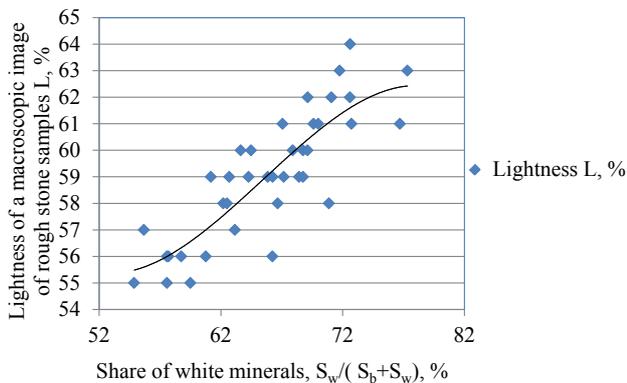


Fig. 5. The graph of dependence of lightness changes in rough stone on the share of white minerals

Fig. 6 shows that the types of Pokostivskiy granodiorite of different lightness are characterized by different values of the areas of dark- and light-colored minerals shown in Table 4.

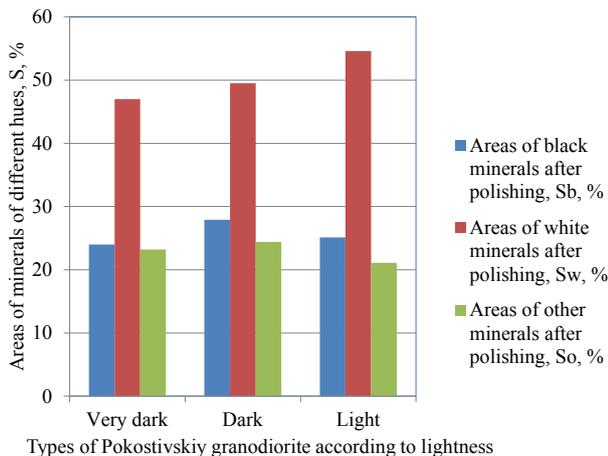


Fig. 6. Description of structural features of polished samples of the types of Pokostivskiy granodiorite of different lightness

Comparison of the average lightness of different types of rough and polished samples of Pokostivskiy granodiorite indicates that it is impossible to determine the differences in the lightness of rough stone, because in addition to black and white there are colored minerals with a certain lightness. Therefore, determination of the types of Pokostivskiy granodiorite in terms of lightness is based on the ratio of black and light minerals.

Table 4

Description of polished samples of the types of Pokostivskiy granodiorite of different lightness

Type of stone according to lightness	Areas of black minerals, S _b , %	Areas of white minerals, S _w , %	Areas of other minerals S _o , %	Average lightness L _{avg} , %
Very dark	29.8	47	23.2	61.16
Dark	26.1	49.5	24.4	65.52
Light	24.3	54.6	21.1	69.32

After polishing of natural stone, its lightness also depends on the share of white minerals, stone surface lightness increases with the increase in the areas of light minerals.

The graph of dependence of lightness changes in the polished stone samples on the ratio of the area of white minerals to the area of black minerals was constructed (Fig. 7).

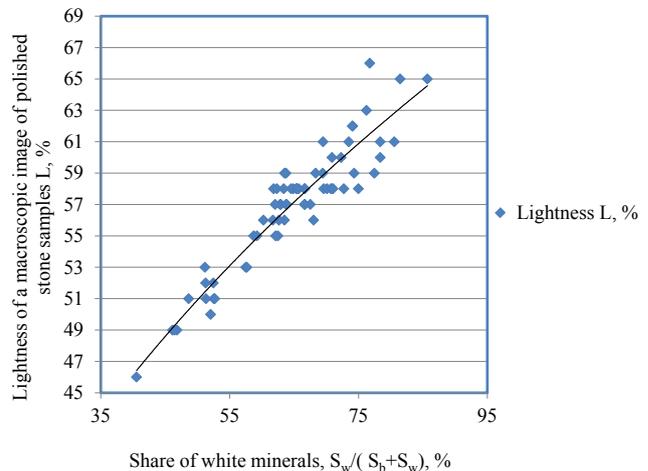


Fig. 7. The graph of dependence of lightness changes in the polished stone on the share of white minerals

Depending on the share of white minerals, lightness L for Pokostivskiy granodiorite is described a power-law relationship:

$$L = 70.145 \left(\frac{S_w}{S_b + S_w} \right)^{0.4651}, \quad (2)$$

where L – lightness, %; S_w – areas of white minerals, %; S_b – areas of black minerals, %.

The approximation reliability is R²=0.8916.

The generalized description of the types of Pokostivskiy granodiorite of different hues was compiled as a result of quantitative values of structural features of samples of the types of Pokostivskiy granodiorite of different lightness and based on previous studies (Fig. 8).

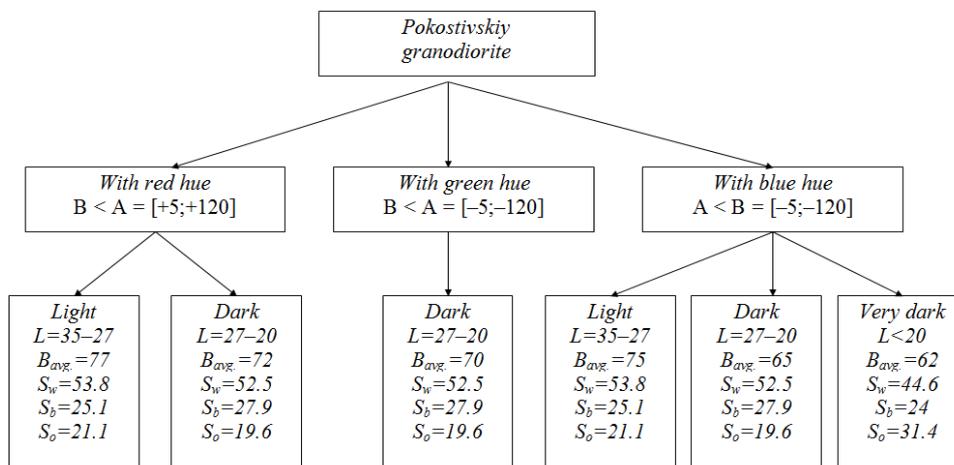


Fig. 8. Description of the basic types of Pokostivskiy granodiorite: where L – stone surface lightness after mechanical polishing, %; A, B – color coordinates of stone surface samples, units; B_{avg} – average gloss of stone sample surface, GU; S_w – areas of white minerals before polishing, %; S_b – areas of black minerals before polishing, %; S_o – areas of other minerals before polishing, %

Thus, the generalized description of different types of Pokostivskiy granodiorite will allow determining the blocks of different hues using the developed method for selecting the stone processing technology, ensuring minimum lightness difference between the types of Pokostivskiy granodiorite of different hues.

6. Discussion of results of research of grinding-polishing impact on stone gloss and lightness

Natural facing stone has uneven color, clearly observed after polishing. When laying natural stone tiles with different hues, there is a difference in the perception by the human visual analyzer. Nowadays, the batch of tiles made of Pokostivskiy granodiorite of one hue is created by sorting finished products, which increases working hours. Also, making a lightness-uniform batch of tiles requires natural stone block processing with a margin of 30 %. Excess finished products that did not match are stored in the company warehouse and expect another customer.

In previous publications [1, 3, 18], the authors have proved that lightness can be managed by various mechanical and chemical methods. The problem was that rough Pokostivskiy granodiorite cannot be classified by according to lightness visually. Therefore, the lightness management method was selected after stone product finishing. This leads to additional material costs. This can be avoided if granodiorite lightness in raw stone blocks is quantified, which allows using a particular lightness management method at the initial stone processing stage.

It was found that the lightness differences in various types of Pokostivskiy granodiorite are not observed during the macroscopic study of rough samples (lightness L of rough samples is: 59.5 % – for light types, 59.0 % – for dark types, 58.8 % – for very dark types). The average ratio of lightness (L components, Lab system) of the types of Pokostivskiy granodiorite of different lightness is almost the same. It was revealed that the areas of dark- and light-colored minerals (Fig. 4) have a direct impact on the stone lightness. Stone surface lightness increases with the increase in

the areas of light-colored minerals (Fig. 5). Herewith, the description of the basic types of Pokostivskiy granodiorite according to the hue that contains data about the characteristics of rough samples was compiled. The present research will allow developing a rapid method for determining the lightness of Pokostivskiy granodiorite in raw stone blocks before machining, which makes it easier for stone processing enterprises to select raw materials.

7. Conclusions

The patterns of lightness changes in rough and polished samples of the types of Pokostivskiy granodiorite of different hues depending on the ratio of the areas of white minerals to the areas of black minerals, described by the polynomial and power-law relationships respectively were determined. In rough samples, the L component (LAB system) ranges within 55–64, in polished samples – 46–66.

The method of determining the types of Pokostivskiy granodiorite of different hues using digital image processing by image segmentation into objects and background was developed. This method allows identifying the tone of Pokostivskiy granodiorite in raw stone blocks without preliminary processing. Other methods do not provide such opportunities because Pokostivskiy granodiorite in raw blocks has almost the same tone and it varies widely in finished products only after processing.

The generalized description of the types of Pokostivskiy granodiorite of different hues was compiled. This will allow identifying the blocks different in lightness and hue on stone processing enterprises based on computer stone surface image processing and comparison with the classification for solving problems of selecting the lightness of the polished surface. According to the area of white, black and other minerals, Pokostivskiy granodiorite is divided into very dark, dark, light. The average area of white, black and other minerals of rough Pokostivskiy granodiorite is, respectively, as follows: very dark – 44.6 %, 24 %, 31.4 %; dark – 52.5 %, 27.9 %, 19.6 %; light – 53.8 %, 25.1 %, 21.1 %.

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