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Laser cleaning of plaster

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Abstract. The paper is devoted to experimental study of laser cleaning of plaster. Nowadays laser technologies are widely used in the preservation of Cultural Heritage, and laser cleaning is most frequently used technique in artworks conservation. However, laser cleaning of plaster sculptures and architectural decorations is not yet established. Experimental results of divestment of model samples and 20th century plaster sculpture by means of pulsed Nd:YAG laser (generating at wavelengths of 1064 nm, 532 nm and 355 nm) and fiber laser with wavelength of 1064 nm are presented.

Keywords: Laser cleaning, Cultural Heritage, artworks, restoration, plaster

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Материалы конференции

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Лазерная очистка гипса

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Аннотация. Статья посвящена экспериментальному исследованию лазерной очистки гипса. В настоящее время лазерные технологии широко применяются в области сохранения культурного наследия, и лазерная очистка используется наиболее часто в реставрации произведений искусства. Однако лазерная очистка гипсовых скульптур и архитектурных элементов пока еще не получила практического применения. Представлены экспериментальные результаты очистки модельных образцов и гипсовой скульптуры XX века с помощью импульсного Nd:YAG-лазера, генерирующего на длинах волн 1064 нм, 532 нм и 355 нм, а также волоконного лазера с длиной волны 1064 нм.

Ключевые слова: лазерная очистка, культурное наследие, произведения искусства, реставрация, гипс

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Introduction

In the last two decades, laser technologies have been increasingly used in the preservation of cultural heritage. The most widely used technology is laser cleaning, which is used in restoration and conservation to remove natural deposits and anthropogenic pollutants from the surface of monuments [1]. Currently, the most refined cleaning of stone, in particular, marble and limestone. As for other materials, including gypsum, each of them requires the development of an individual laser application methodology, which requires targeted research.

Due to the simplicity of plaster processing, it is widely used in the creation of sculptures and small architectural forms, including stucco decorations and bas-reliefs. However, this material is very fragile, porous and gyrosopic, which makes the restoration of plaster objects a very difficult task. Traditional methods of gypsum restoration cleaning based on the use of chemical and mechanical methods are ineffective, and sometimes lead to significant surface damage that causes irreversible changes in the state of preservation of monuments. With this in mind, laser cleaning is potentially a promising alternative method for the preservation of plaster artifacts, due to the possibility of a delicate and controlled effect on the surface to be cleaned.

Currently, very few publications are devoted to laser cleaning of plaster in the scientific literature [1–3]. This indicates the scientific novelty of research in this area. In this paper, experimental studies were conducted on the possibility of using laser cleaning of gypsum using Nd:YAG and fiber lasers operating at different wavelengths and having different pulse durations in order to determine the optimal laser treatment modes.

Materials and methods

Model samples were prepared for experiments on laser cleaning of gypsum. They were small (about 3×3 cm² in size) plates, on the surface of which dust pollution, typical of gypsum objects in the collections of many museums, was artificially simulated. To do this, graphite dust was applied to the surface of plaster plates and rubbed into it (Fig. 1).

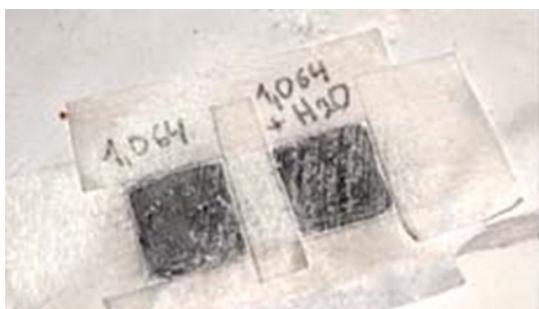


Fig.1. Plaster samples with artificial contaminations

Three different lasers were used to clean the model samples:

1. Pulsed solid-state Nd:YAG laser with a tube pump and a compact emitter connected to the power supply unit by a flexible cable, inside of which there is a water cooling tube and electrical wires. The successful ergonomic design of the emitter allows one to hold it in hands and easily move it relative to the surface to be treated (Fig. 5) This laser operates in a Q-switched mode at two wavelengths, at the main wavelength of 1064 nm and at the wavelength of the second harmonic of 532 nm and has a pulse duration of 20 ns and a beam diameter of 6 mm. In the experiments, the pulse energy was 100 mJ, and the pulse repetition rate was 2 Hz.
2. Pulsed fiber ytterbium laser with a wavelength of 1064 nm, a pulse duration of 100 ns and a pulse repetition rate of up to 100 kHz. This laser is also equipped with a small-sized “gun” that can be held in hands during the cleaning process. The maximum average laser power is 100 watts, but in experiments the power level did not exceed 10 W. The laser radiation spot is a rectangle about 1×20 mm in size, which is formed by separate consecutive pulses deployed in a line.
3. Pulsed solid-state Nd:YAG lamp-pumped laser operating at a wavelength of the 3rd harmonic of 355 nm in Q-switched modulation mode. It has a maximum average power of 5 W, a pulse duration of 10 ns and a pulse repetition rate of up to 50 kHz. This is a commercial laser designed for marking products of the electronic industry, as a result of which it is equipped with a system of two galvanometric mirrors that provide high-speed scanning of the laser beam along a given trajectory, as well as a focusing system that forms a spot in the focal plane with a diameter of about 10 microns. In our experiments, gypsum was treated with a defocused beam in order to eliminate its mechanical damage.

The condition of the samples before and after laser cleaning was monitored using an optical microscope. In addition, the reflection coefficient and the color characteristics of the surface were measured. These measurements were carried out using a portable spectrophotometer Spectro Guide (BYK Gardner GmbH, Germany). The color characteristics were monitored using an international color scale The CIE (Commission International de l'Eclairage) 1976 ($L^*a^*b^*$), or briefly CIE LAB system, which is widely used for recording the chromatic coordinates. This system, referred to as colorimetry, is an effective tool for visualizing the color. The symbols L^* , a^* , and b^* represent the following: a^* is a red-green component of color (it can be varied in the range from or -127 (green) up to $+127$ (red)), b^* is a yellow-blue component of color (it can be varied in the range from or -127 (blue) up to $+127$ (yellow)), and L^* is a brightness, which characterizes black-white color shades ($L^* = 0$ for black, and $L^* = 100$ for white). The change of characteristics of the analyzed surface may be found by means of measurements of differences in reflectance spectrum. Various factors, such as deterioration processes in the image area, materials content, surface hardness and granules size (in case of porous materials), can influence changes of colors.

Results and discussion

The choice of lasers for cleaning in monument restoration is usually based on consideration of their optical properties. The general rule is that in order to reduce the risk of damage to monuments as a result of heating their surface during laser treatment, it is necessary to choose the laser wavelength in such a way that a high reflection coefficient is provided for this wavelength. But at the same time, the pollution layer, on the contrary, must effectively absorb laser radiation. With this in mind, at the initial stage of the experiments, measurements of the reflection coefficient of pure plaster (before artificial contamination) were carried out, which showed that it has a high reflection in a wide spectral range with a maximum in the range of 950–1050 nm (Fig. 2). Taking this into account, lasers with a wavelength of about 1 micron are well suited for cleaning plaster, including an Nd:YAG laser (with a primary wavelength of 1064 nm) and a fiber laser (with the same wavelength). As for the second and third harmonics of the Nd:YAG laser radiation, they were supposed to be used to select optimal laser processing modes, including, among other things, as a result of varying the wavelength when working with both prototypes and real artifacts.

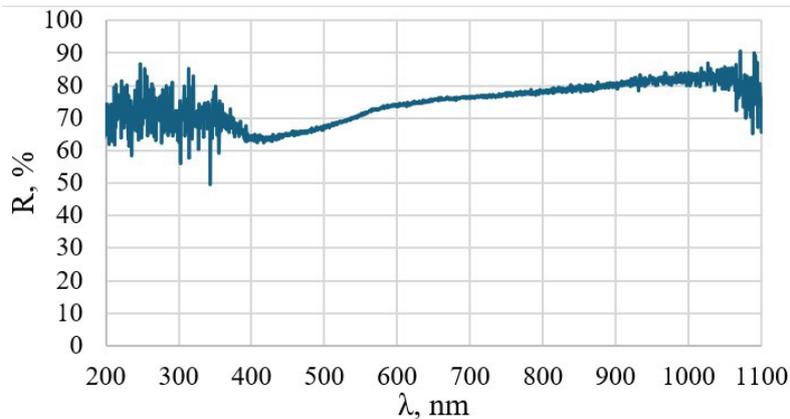


Fig. 2. Reflectance spectrum of pure plaster

When working with all lasers, even with comparable values of radiation energy density, different results were obtained in terms of the effectiveness of laser cleaning and related effects. In all cases, surface contamination was removed, but sometimes a number of negative effects were noted. In particular, mechanical damage and discoloration of the plaster could occur.

Mechanical damage during operation with all lasers was eliminated due to careful selection of the energy density of the laser radiation. At the same time, the delicate cleaning technique consists in starting work by setting the lowest values of this parameter, gradually (step by step) increasing it until the effect of removing impurities is achieved, and individually when working with each sample. As for the color change (plaster acquired a yellowish tinge instead of the original white color (Fig. 3)), then this problem was most effectively solved only when working with Nd:YAG with a wavelength of 355 nm.

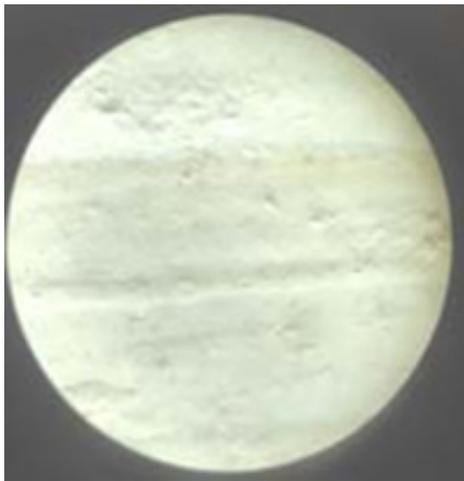


Fig. 3. Plaster model sample: the upper part is pure plaster, the lower part is the area from which graphite was removed using a laser

Fig. 4 shows the color characteristics of plaster after cleaning with various types of lasers. From this diagram, it can be seen that for the Nd:YAG laser with a wavelength of 1064 nm, the value of parameter b^* increased by 8 units (offset to the yellow side) compared with the sample of pure gypsum, and the value of parameter a^* increased by 1.7 units (offset to the red side). The L parameter has also noticeably deteriorated. At the same time, despite the same wavelength of the fiber laser, the yellowing effect is much less pronounced for it, and is almost completely absent when working with the third harmonic of the Nd:YAG laser. Another interesting experimental fact should be noted – radiation with a wavelength of 355 nm makes it possible to lighten a surface that has turned yellow when working with an Nd:YAG laser with a wavelength of 1064 nm.

It should be noted that all the experimental results listed above are purely empirical and await explanation. Mechanical damage to the plaster surface by an Nd:YAG laser with a wavelength of 1064 nm and their less pronounced character when treated with a fiber laser with the same wavelength can be explained by the difference in pulse duration (20 ns and 100 ns, respectively), which leads to a higher peak radiation power in the first case.

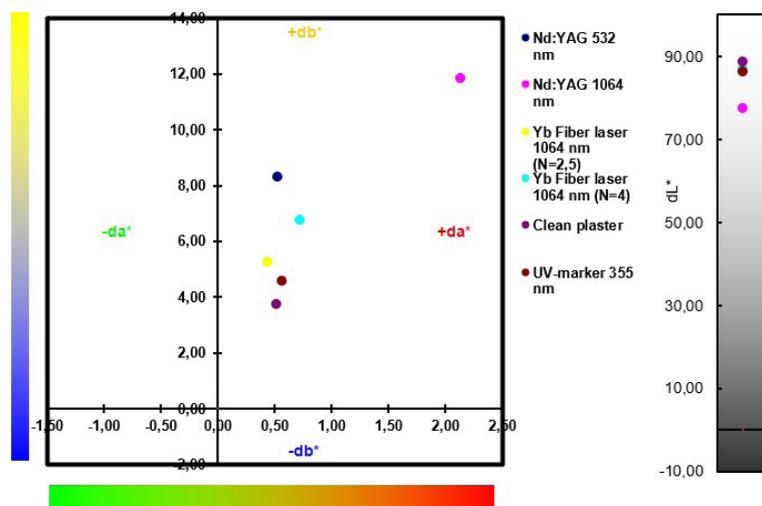


Fig. 4. Color characteristics of plaster after cleaning with various types of lasers

As for the answer to the question of the causes of plaster yellowing when working with a laser with a wavelength of 1064 nm and the absence of the same effect at a wavelength of 355 nm, this requires additional research. However, this has long been a well-known problem in laser restoration, which was first noted when cleaning marble and limestone monuments [4]. There are several hypotheses explaining this phenomenon, but experts still have not come to a consensus [5]. Apparently, the same is the case in the case of plaster.

In addition to working with model samples, in this work, trial clearings of the monument of the 20th century were carried out – the plaster bust of General A.N. Maksimenkov, the first head of the Military Medical Museum (St. Petersburg). On the surface of this monument there are multiple (total number of layers – 6) oil paints, which the museum experts would like to remove. In the experiments, we used a 2-wavelength (1064 nm and 532 nm) Nd:YAG laser described

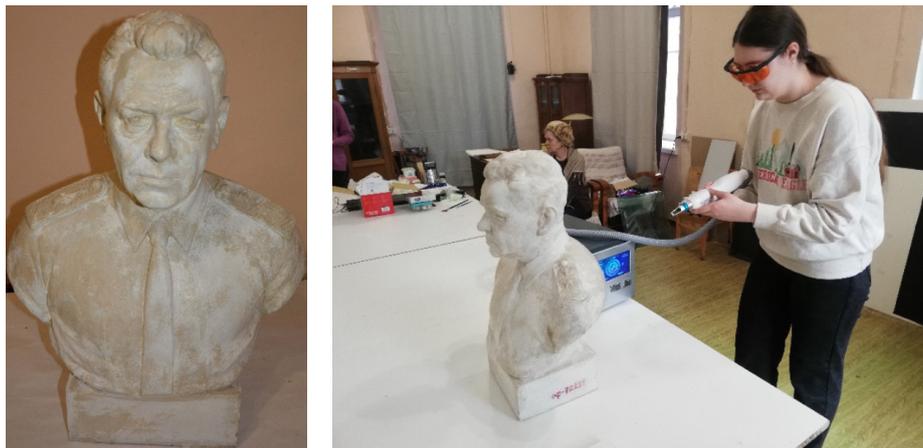


Fig. 5. Plaster sculptural portrait of general A.N. Maksimenkov: general view (left), process of laser cleaning (right)

in the section ‘Materials and Methods’. Unfortunately, cleaning at both wavelengths proved ineffective, since the laser allowed only the topmost layer of paint to be removed. Nevertheless, an interesting practical result of the experiments is the fact that wet laser cleaning proved to be more effective than dry. The same can be said about the advantage of the wavelength of 532 nm compared to 1064 nm. Apparently, for the restoration of this monument, it is necessary to use a cleaning technique combining the use of a laser and chemical treatment, as described in [6]. But this will be the next stage of our work, the results of which we will report after its completion.

Conclusion

In this paper, a comparative assessment of the effectiveness of laser cleaning of gypsum surfaces using three types of lasers is carried out. Based on the experimental studies carried out, it can be concluded that the best results in removing artificially created impurities from graphite dust are provided by a pulsed Nd:YAG laser with a wavelength of 355 nm and a pulse duration of 10 ns.

Since the work did not investigate the removal of other types of contamination of monuments, and the restoration of the sculptural portrait of general A. Maksimenkov is still ongoing, the results obtained should be considered preliminary. The authors of the article plan to continue their research and publish their results in a separate article.

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