LASER CLEANING OF POLYCHROME ARTWORKS. CASE STUDY ON GRAFFITI

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One of the most complex applications of lasers on the Cultural Heritage field consists in laser cleaning: the removal of the adherent deposits without affecting the original substrates. The laser devices and work regimes used over time in the field of restoration and conservation of Cultural Heritage are various, but so far most of the studies on the graffiti were attentive to removing the layers of paint. The present research is focused on preserving graffiti, as a contemporary art form. The interaction between two different wavelengths of a Nd:YAG Q-switched laser (1064 nm and 532 nm) and polychrome substrates of graffiti has been evaluated using microscopy and colorimetry techniques.

Keywords: laser cleaning, polychrome, adherent deposits, graffiti.

1. Introduction

Paintings are multilayer polychrome structures that can be applied on cardboard, wood, glass, textile etc. The polychrome substrates contain natural or artificial pigments mixed with binders and the type of the binder defines the painting as: gouache, tempera, oil or acrylic.[1]

Over the years, the polychrome surfaces can suffer changes due to exposure to certain factors such as pollutants, humidity, temperature, UV radiation, dust etc. The removal of the adherent deposits on the surface must be done with outmost precaution and the domain is in a constant expansion, constantly improving and developing new cleaning technologies and techniques.

Since the opening of a modern meaning of restoration by Brandi (1963), chemistry has been mostly involved, providing reactants, poultices for consolidation and cleaning, coatings for protection. Physics has also given very important optical methods such as microscopy, colorimetry, photogrammetry, as well as the use of X-rays for diagnosis.[2-4] Laser techniques in CH field emerged about fifty years ago (Asmus, 1968), providing not only a new approach for restoration procedures, but

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also non or micro-destructive methods for diagnosis, such as Laser Induced Fluorescence and Laser Induced Breakdown Spectroscopy [5-8].

One of the most complex applications of lasers on the Cultural Heritage field consists in laser cleaning: the removal of the adherent deposits without affecting the original substrates.[9,10] The lasers produce instantaneous vaporization of the adherent deposits layers through a photo-chemical process called laser ablation. Laser radiation facilitates the selective cleaning of the surfaces without affecting the original materials, if the correct working regime is employed, of course. Besides the wavelength and the frequency, the fluency is one of the most important parameters that can be attuned in order to obtain a safe cleaning of the artworks. The fluency is the energy per spot area, as described in *Formula 1*.

$$F\ (mJ/cm^2) = E\ (mJ) / A_{spot}\ (cm^2) \qquad (1)$$

An effective cleaning is obtained when selecting a working regime with a fluency high enough to clean the adherent deposits, but low enough so it does not affect the original substrate. The cleaning tests are usually conducted starting with low fluencies that are progressively increased without exceeding the ablation threshold specific to the original substrate. The main advantages of the laser cleaning, compared to the traditional cleaning methods, are: non-contact techniques, with increased sensitivity, selectivity, versatility, follows closely the surface profile and it does not use or produce chemical residues [11].

The first complex laser cleaning campaign in Romania took place in 2004 at the Lady's Church from Bucharest. The main subject was laser cleaning of the stone columns from the atrium of the church, but some polychrome mural areas were also cleaned. The equipment used was a portable Q-switched Nd:YAG laser that emits at 4 wavelengths: 1064 nm, 532 nm, 355 nm and 266 nm. The laser cleaning regime was selected after a complex study regarding the effect of the laser on type of stone used in the edification of the columns.[12] At this time, laser cleaning is a method well known in the Romanian conservation-restoration field, as it was applied on numerous monuments and artworks, organic and inorganic, such as: stone, metal, paper, leather, parchment, paintings, wood etc. Great results were obtained on stone surfaces that were affected by frost/defrost or suffered delamination, cases in which the cleaning was obtained without inducing additional stress to the already fragile stone substrate using laser radiation.[13,14]

2. State of the art and discussion over a selection of case studies

The laser devices and work regimes used over time in the field of restoration and conservation of Cultural Heritage are varied and the purpose of this section is to provide an overview of the most used and to provide some examples of application. Currently, laser research is focused on improving controllable layer elimination, but also on developing new methods for multidisciplinary approach and real time investigation.[15]

As the research field evolves, the art domain progresses as well. Therefore, an overview of the studies conducted so far is mandatory in order to determine the state of the art of the laser cleaning applications on polychrome modern and contemporary artworks. The most interesting papers that approached certain cases with particular glitches were selected and comprised in a synthesis in order to create a reference instrument for future restoration and preventive conservation applications.

In order to evaluate the state of the art of the field and the applications of lasers on polychrome materials, a synthesis of twenty-one studies published in ISI indexed journals between 1998 and 2017 was made. [16-36]

The lasers used in the selected timeframe for laser cleaning of polychrome artworks were: Nd:YAG (55%), Er:YAG (15%) and KrF excimer (30%).

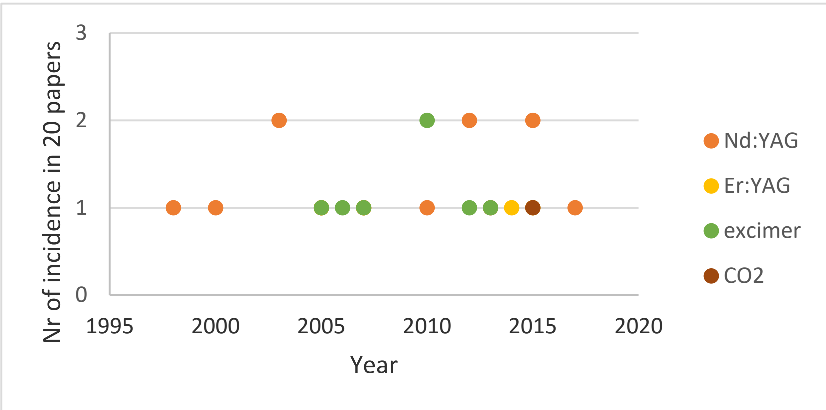


Fig. 1. Laser type distribution over the 1998-2017 timeline*

**based on the papers selected in the synthesis*

In Fig. 1 we have depicted the distribution of the types of lasers used in the field of polychrome surface cleaning in the selected time frame: 1998-2017. Although in 2000 studies employing Er:YAG lasers showed interest, afterwards it had a fairly long stagnation. Lately, however, it has returned to use and it seems to have proved to be a successful tool in cleaning polychromic surfaces on canvas and paintings on the easel. From what can observed, the research field was mainly focused on the use of Nd:YAG lasers, because they are portable systems, they are much more affordable than other types of lasers and can provide a range of wavelengths in IR, VIS and UV spectral domains.

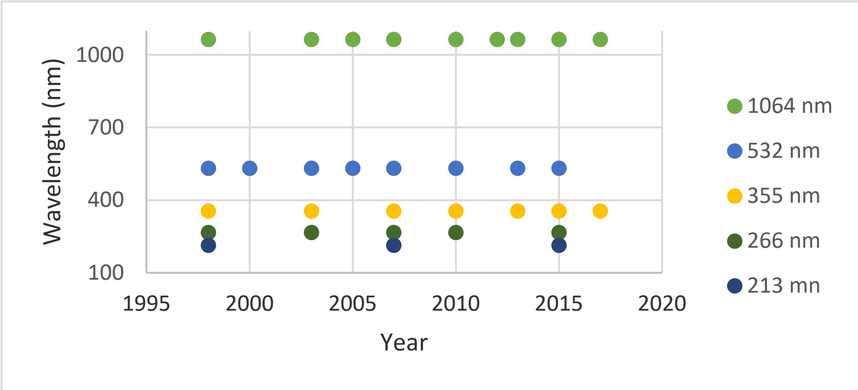


Fig. 2. Nd:YAG wavelength statistic for 1998-2017*

**based on the papers selected in the synthesis*

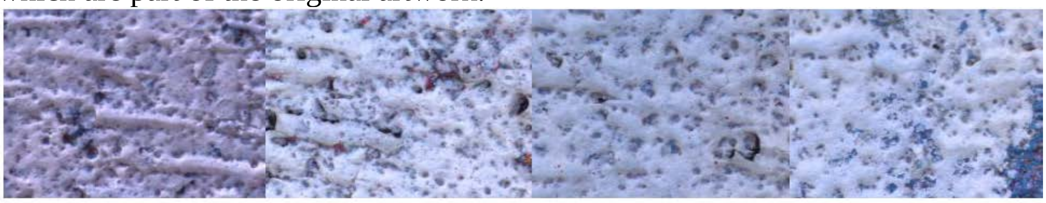
According to Fig. 2, the wavelengths in the UV and VIS domain had the most applications over the years in the field of laser cleaning of polychrome surfaces. The selection of the working regime was based on the use of laser parameters that show efficient cleaning without causing yellowing, darkening or discoloration of the surface.

3. Results and discussions

The laser used for the cleaning test is a solid state laser: Nd:YAG working in Q-switched mode, with a pulse duration of 4 ns and variable frequencies from 1 to 20 Hz. The laser can be operated at 4 wavelengths: 1064 nm, 532 nm, 355 nm and 266 nm and has 2 mobile articulated arms that allow full coverage for large surface cleaning procedures.

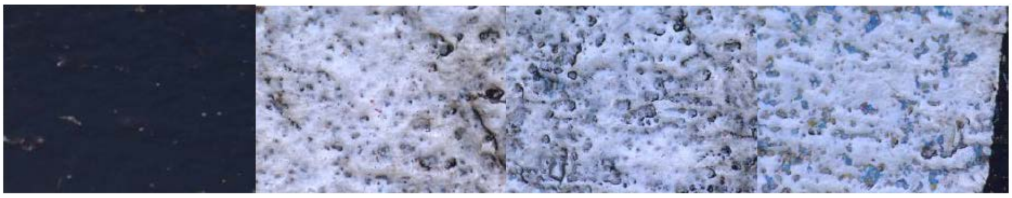
The interaction between two different wavelengths of a YAG:Nd Q-switched laser (1064 nm and 532 nm) and the polychrome substrates of graffiti has been evaluated using microscopy and colorimetry techniques. The graffiti painting was artificially soiled with black smoke in order to simulate one of the most common adherent deposits that affect the mural paintings.

The results obtained on the graffiti are presented and discussed in the following sections. We must underline that the purpose of these tests is to obtain an efficient removal of the adherent deposits whilst preserving the graffiti layers which are part of the original artwork.



Original *0,58 J/cm^2* *0,75 J/cm^2* *0,82 J/cm^2*

Fig. 3: Microscopic images of *Graffiti area 1*, λ=1064 nm, ν= 10 Hz, Fluency: 0,5 – 0,8 J/cm^2



Artificially soiled *0,25 J/cm²* *0,3 J/cm²* *0,4 J/cm²*

Fig. 4: Microscopic images of *Graffiti area 1*, λ=532 nm, ν= 10 Hz, Fluency: 0,25 – 0,4 J/cm^2

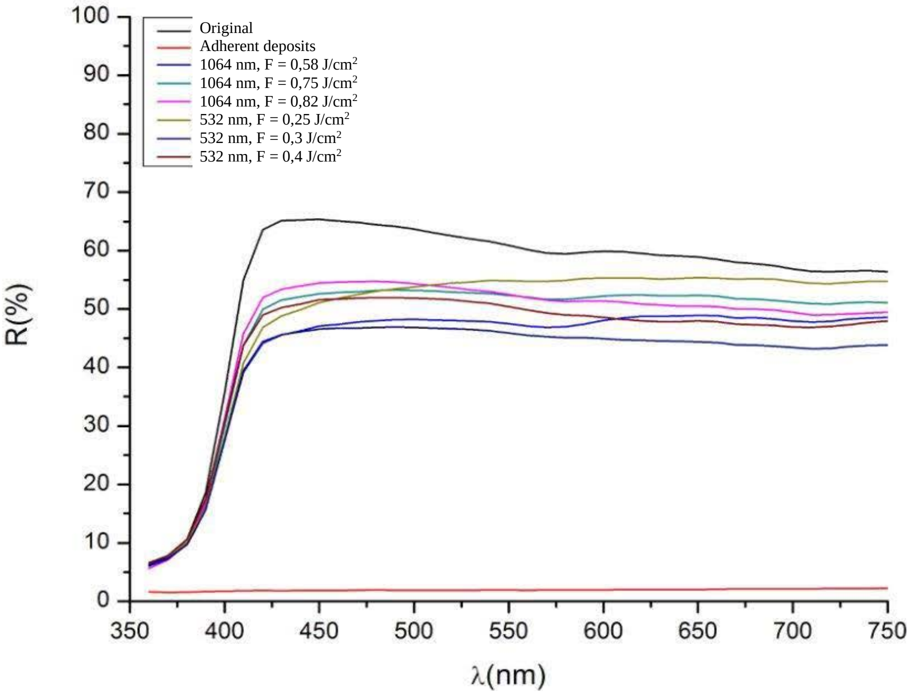


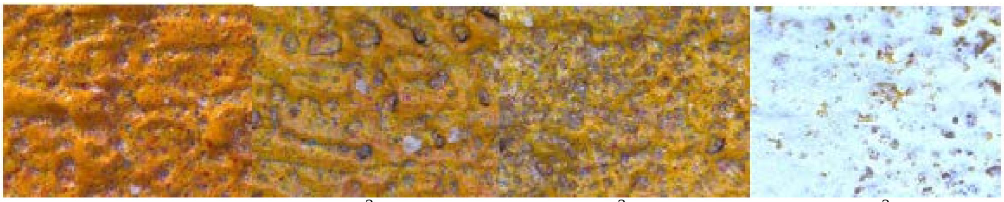
Fig. 5. UV-VIS spectrum for 1064 nm and 532 nm laser cleaning tests of *Graffiti area 1*

Table 1

Colorimetry results for laser cleaning @1064 nm and @532 nm of *Graffiti area 1*

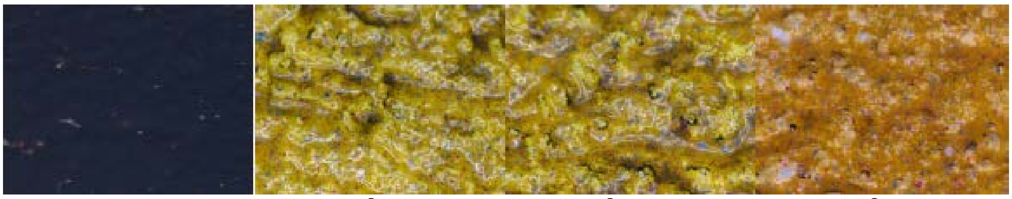
CIE Lab	0,58 J/cm^2	0.75 J/cm^2	0,82 J/cm^2	0,25 J/cm^2	0,3 J/cm^2	0,4 J/cm^2
dL	-6,06	-8,42	-9,65	-8,5	-7,18	-5,27
da*	-0,36	0,19	-0,36	-0,11	-0,07	-1,32
db*	4.87	2.53	1,15	6.72	4.25	3,41
dE	7.78	8.79	9.72	10.84	8.34	6.41

In the cases where the radiation @1064 nm was used, the luminosity values increase with the fluency ones and the sample cleaned with 0,58 J/cm^2 has the closest values to the original. From the analyses of the color axes we can see that there are no significant changes from the original sample. The microscopy investigations results are proof that none of the cleaning regimes induced changes in the morphology of the surfaces.



Original *0,58 J/cm^2* *0,75 J/cm^2* *0,82 J/cm^2*

Fig. 6: Microscopic images of *Graffiti area 2*, λ=1064 nm, ν= 10 Hz, Fluency: 0,5 – 0,8 J/cm^2



Artificially soiled *0,25 J/cm^2* *0,3 J/cm^2* *0,4 J/cm^2*

Fig. 7: Microscopic images of *Graffiti area 2*, λ=532 nm, ν= 10 Hz, Fluency: 0,25 – 0,4 J/cm^2

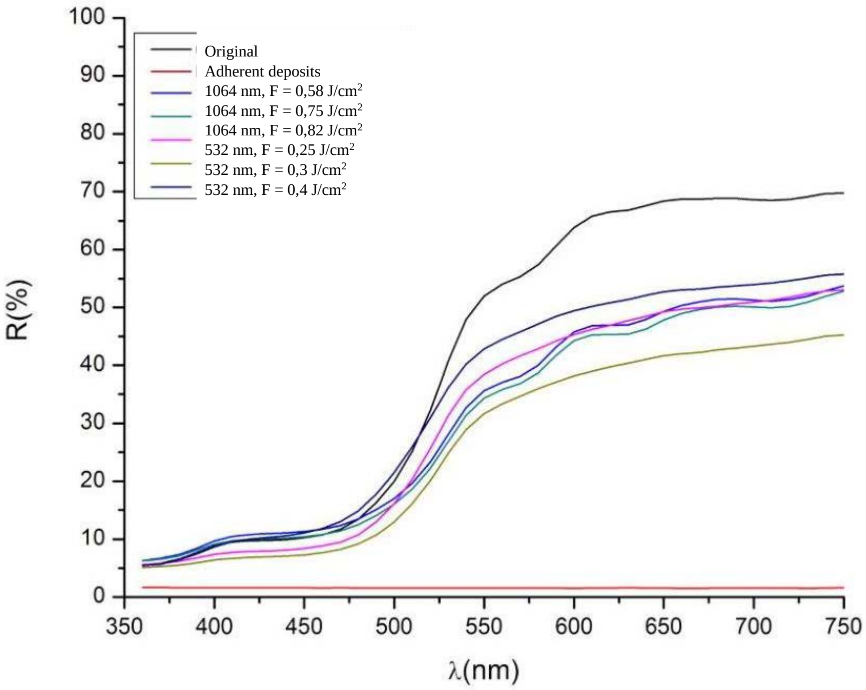


Fig. 8. UV-VIS spectrum for 1064 nm and 532 nm laser cleaning tests of *Graffiti area 2*

Table 2

Colorimetry results for laser cleaning @1064 nm and @532 nm of *Graffiti area 2*

CIE Lab	0,58 J/cm^2	0.75 J/cm^2	0,82 J/cm^2	0,25 J/cm^2	0,3 J/cm^2	0,4 J/cm^2
dL	-6,57	-4,44	9,77	-9,75	-12,75	-5,1
da*	-3,12	-1,27	-16.36	-7,31	-8,72	-10,39
db*	-15,5	-7,54	-57,28	-13,16	-15,86	-14,76
dE	17.12	8.84	60.37	17.94	22.14	18.76

In the areas cleaned with 1064 nm at a fluency of 0,82 J/cm^2 the paint player was removed from the object's substrate, therefore in the case of this specific pigment, the ablation threshold was reached. In the areas cleaned with 532 nm wavelength we observe a slight discoloration present in the case of the 0,4 J/cm^2 fluency. A good cleaning is obtained using 1064 nm @ 0,75 J/cm^2 and 532 nm @ 0,3 J/cm^2, but clearly the regime using the visible wavelength is the most effective one.

4. Conclusions

Following the studies comprised in the synthesis, we have been able to study the interaction between laser and polychrome surfaces and evaluate the proper laser parameters for an efficient cleaning. The results of the researches have proved the proficiency of the cleaning using laser radiation, especially for the surfaces found in a high deterioration/degradation state.

The laser cleaning method, with its high degree of control, has good results in removing the adherent deposits without damaging the original substrate. Good results were obtained with both wavelengths and we can conclude that the most efficient working regime depends on the type of pigments and binders present in the paint layers.

The present study confirms that the use of Q-switched Nd:YAG lasers at wavelengths of 1064 nm and 532 nm are suitable in general for the cleaning of polychrome surfaces, including graffiti, as its wavelength can be tuned to the physical and chemical characteristics of the artwork, accordingly to the Ishikawa Diagram. This study is part of a complex research project and the investigations will continue on finding the proper cleaning regime for different types of unwanted adherent layers on graffiti substrates.

Through continuous research, laser cleaning applications in the field of Cultural Heritage are now in a fairly advanced stage, but even so, the research continues to unravel new types of materials, objects or applications that imply optimization of the laser cleaning.

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