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Laser cleaning of gilded wood: A comparative study of colour variations induced by irradiation at different wavelengths

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Abstract

There is a growing interest by art conservators for laser cleaning of wood artworks, since traditional cleaning with chemical solvents can be a source of decay, due to the prolonged action of chemicals after the restoration. In this experiment we used excimer and Nd:YAG lasers, emitting radiation in the ultraviolet (248 nm), visible (532 nm) and near infrared (1064 nm), to investigate the effect of laser interaction on gilded wood samples at different wavelengths. Increasing fluence levels were tested to assess threshold values both for surface damage and colour changes. Detailed colorimetric analyses of the irradiated samples show that cleaning effectiveness is related to the emission wavelength, the fluence and the number of pulses.

Keywords: Laser cleaning; Gilded wood; Nd:YAG lasers

1. Introduction

Laser-based techniques are widely used in cultural heritage conservation as advanced tools for cleaning artwork surfaces. Laser cleaning is an established method for the restoration of metal artifacts [1] and for the selective removal of black crusts, or other surface pollutants, from stone or marble sculptures, or architectural surfaces [2,3]. Laser cleaning is controllable with a high precision, reducing the risks of damaging the underlying surface. Recent advancements in laser cleaning, such as the design of new types of lasers, are making this method a reliable alternative to traditional cleaning procedures.

Cleaning of paintings is also a field where intense research activities are carried out [4], while only a small number of reports can be found about the cleaning of wooden artifacts [5,6], and very few papers can be found about treatment of gilded wood [7].

The main advantage of laser cleaning of gilded wood is in the prevention of damages due to the action of chemical solvents, that are generally used in traditional cleaning procedures. Laser treatment also allows a more controllable cleaning action.

In this paper we studied the interaction of laser radiation with a layer of gold leaf to verify the applicability of laser cleaning to gilded wood restoration. In particular, we report on systematic investigations of the effect of laser cleaning at different laser wavelengths on a suitable set of samples, representative of gilded wood objects, like sculptures or frames. We used non-destructive colorimetric analyses to measure chromatic variations induced by laser irradiation.

2. Experimental

2.1. Model samples

We realized the samples for the cleaning tests on the basis of the information we inferred from both chemical and physical analyses carried out on a piece of a golden wooden frame of the XVIII century (Fig. 1a). A typical sample is a layered structure

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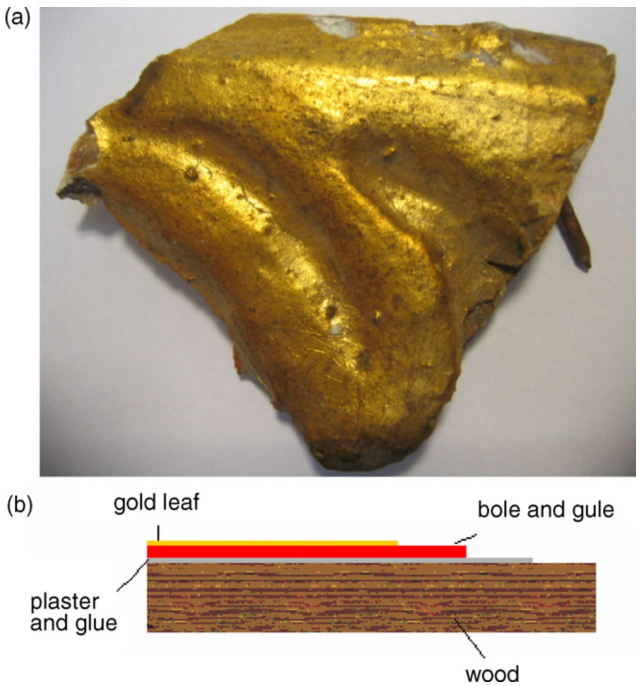

Fig. 1. (a) Piece of a golden wood frame (XVIII century) and (b) stratification of a typical model sample representative of usual wooden sculptures and frames with gold leaf.

covering a wooden support. Starting from within, the layers are made from variable thicknesses of plaster, glue and bole. On top of these is the very thin layer of the gold leaf (Fig. 1b). Because of the combined effects of aging and exposition to pollutants, it is impossible to define standards for the dirt layering on artworks. Thus, we used either soot, soil or graphite (synthetic graphite powder, 1–2 μm, from Aldrich) to model the dirt layer on some of the analyzed samples.

2.2. Laser irradiations

We used the following lasers for our cleaning tests: (a) a Q-switched Nd:YAG laser (Surelite SL-20, Continuum) emitting NIR pulses (λ = 1064 nm, τ = 7 ns), equipped with a second-harmonic generation device to obtain vis pulses (λ = 532 nm, τ = 7 ns), and (b) a KrF excimer laser (LEXtra 50, Lambda Physik) emitting UV pulses (λ = 248 nm, τ = 20 ns).

The Nd:YAG laser beam has a Gaussian profile whose central area is uniform enough to our purposes, whereas the KrF excimer laser beam profile is homogenized by means of an optical system. The areas of interest on the sample surface are selected through a circular aperture having a diameter of 8 mm. For fixed values of laser energy and spot size, the fluence is varied through an attenuator.

We started by irradiating clean samples with increasing fluences at the three wavelengths, to assess the laser damage threshold (LDT) fluence both for surface morphological alteration and colour change. Afterwards, we performed cleaning tests on soiled samples, studying the cleaning action by varying the number (N) of laser pulses.

2.3. Colorimetric analyses

We used a Minolta CM-2600d spectrophotometer to monitor the spectral reflectance factors (SRF) on each sample and to characterize its chromatic properties. This portable device is equipped with a 52-mm diameter integrating sphere. It works in the d/8 illumination-viewing geometry and its spectral sensitivity ranges from 400 to 740 nm. This instrument capability to return diffuse radiation-related quantities (SCE mode, i.e. Specular Component Excluded) makes it a very useful tool for the colorimetry of those surfaces showing a high degree of specular reflectance, where the colour appearance is a serious concern. SRF changes are described in terms of colorimetric values by the CIELAB 1976 colour space, referred to the D65 illuminant and to the CIE 1964 supplementary standard observer [8]. The magnitude of the colour change is calculated by the colour difference (Euclidian) distance expressed as:

$$\Delta E^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \quad (1)$$

where ΔL^* is the lightness difference, Δa^* the red/green difference, Δb^* is the yellow/blue difference.

Ten spectra are averaged to obtain one data point, in order to quantify the uncertainties of both the SRF values, at every single wavelength and every colour coordinate for each investigated area.

3. Results and discussion

Colorimetric analyses performed on the bare samples, at different laser fluences for the three selected laser wavelength, allowed us to define the LDT fluences as the highest fluences for which the colour difference distance with respect to the non-irradiated samples remains very small ($\Delta E^* < 1$). The following LDT fluences were found: $F = (35 \pm 2)$ mJ/cm^2 for UV irradiation, $F = (50 \pm 2)$ mJ/cm^2 for vis irradiation and $F = (200 \pm 9)$ mJ/cm^2 for NIR irradiation, respectively.

The increasing LDT values can be explained in terms of the different absorption of gold leaf in the different spectral ranges (Fig. 2).

We measured cleaning effects by evaluating the magnitude of the ΔE^* values experienced by the dirty areas, with respect to the bare gold leaf, after a certain number of laser pulses (N). We observed that the cleaning action is more effective for the graphite than for other kind of dirt layers, given the same fluences.

The dependence of ΔE^* on N is reported in Fig. 3 for graphite-stained samples irradiated by UV, vis and IR lasers at three fluences.

We selected a fluence $F = (41 \pm 2)$ mJ/cm^2 to perform the cleaning tests by UV radiation. At this value, the magnitude of colour change of the irradiated bare gold leaf with respect to the non-irradiated one is small after one pulse ($N = 1$), but it becomes relevant starting from the second pulse ($N \geq 2$). Anyway, although it exceeds the LDT, it seems to be the most effective in the removal of the dirt layer. We chose a fluence

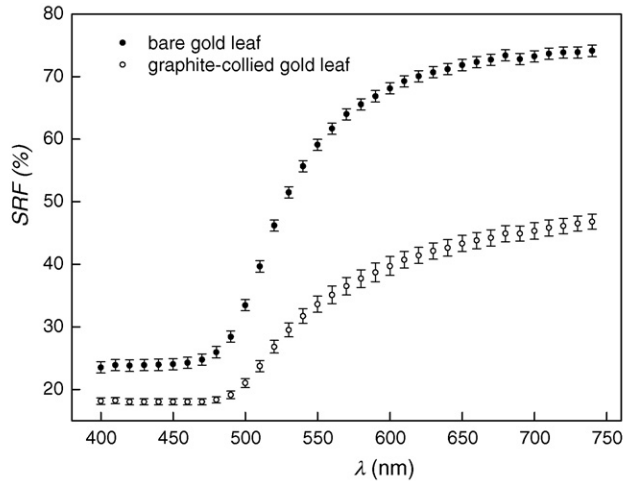

Fig. 2. SFR plot for bare and graphite-stained gold leaf.

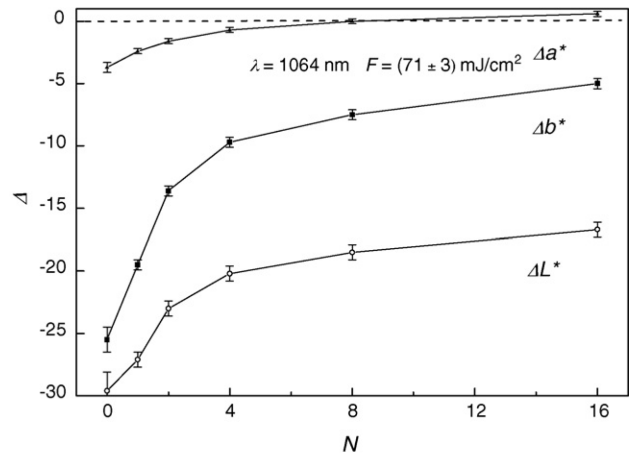

Fig. 4. Colour coordinate variations for each measured area with respect to the bare gold leaf, at $\lambda = 1064$ nm and $F = (71 \pm 3)$ mJ/cm^2.

$F = (59 \pm 2)$ mJ/cm^2 for the tests by vis radiation, since we got no significant variations at lower values. In the experiments with NIR radiation, the fluence $F = (71 \pm 3)$ mJ/cm^2 gave the best results in cleaning. Indeed, at higher fluences, ΔE^* increased significantly.

The behaviour of ΔE^* versus N (Fig. 3) shows that the most effective cleaning occurs when the NIR beam is used, regardless of the graphite amount in the layer.

It is noticeable that when we use the NIR laser the fluence value can be kept below the LDT, and nonetheless we obtain a cleaning effect on the soiled samples. Differently, for the UV and vis lasers some cleaning effects are observable only if we use a higher fluence value than the LDT. This difference of behaviour could be related to the selective absorption of radiation from the dirt layer on the gold leaf in the investigated spectral range (Fig. 2).

The result is then that NIR radiation seems to be the best candidate for cleaning gilded wood. Indeed a fluence sufficient for the cleaning process and non-destructive for the underlying gold leaf can be employed. Whereas, when UV and vis radiation is used, a suitable fluence for the cleaning action could yield destructive effects on the underlying gold leaf after the removal of the graphite layer.

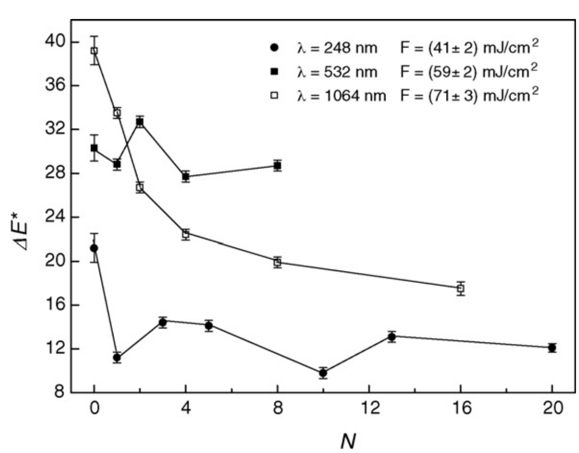

Fig. 3. ΔE^* dependence on N as graphite-stained samples are irradiated by UV, vis and IR lasers at three different laser fluences, as indicated.

We reported in Fig. 4 the colour variations, namely the differences (Δ) of every single colour coordinate with respect to the bare gold leaf ($\Delta = 0$), for the graphite-stained sample irradiated at $\lambda = 1064$ nm and $F = (71 \pm 3)$ mJ/cm^2. This differences decrease with increasing N, and the observed variations are more significant for L^* and b^*. In particular, ΔE^* turns out to be mainly dependent on the L^* coordinate.

4. Conclusions

We investigated the effects of excimer and Nd:YAG laser radiation at three wavelengths on gilded wood samples by measuring colour alterations occurring during the cleaning process.

The different degree of cleaning effectiveness induced by laser irradiation depends on laser wavelength, fluence and on the number of pulses.

NIR laser radiation seems to be the best candidate for the cleaning of gilded wood, because it allows working with laser fluences below the damage threshold of the underlying gold leaf.

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