

Laser restoration method for parchment artefacts

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Cleaning procedures applied on organic substrates of artefacts can be challenging due to their high sensitivity to all external factors, their fragile nature demanding a high precision and accurate monitoring of the cleaning process. This paper reports researches about the effect that the laser restoration procedures (laser cleaning, mainly) induce on organic substrates such as leather and parchment. This study comprises aspects of the ageing of the materials and also specific issues concerning conservation of their photomechanical properties, correlating information obtained using specific scientific methods of analysis such as colorimetry, optical microscopy, shrinkage temperature of the organic fibres and NIR Spectroscopy.

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Keywords: Laser cleaning, Parchment, Shrinkage temperature, Induced ageing assessment

1. Introduction

The goal of this study consists in the appraisal of the restoration scenario development opened by the adaptation of the laser technology in art conservation. Traditional methods used so far rely on mechanical or chemical techniques, but these processes are difficult to control, residues remain present after the process is finished, besides the fact that extensive experiments are needed in order to achieve an optimal result. Laser cleaning is a novel technique that applies to inorganic materials substrates as well as organic ones. It has the potential to provide contactless, chemical-free cleaning of historically important documents, overall providing a high accuracy successful cleaning. However, the advantages that laser cleaning introduces to organic materials – particularly collagenous structures – are still quite limited by the insufficient understanding of the effect of the wavelength or the energy density (fluence level) [1]. Furthermore, optical techniques can be applied on-line to evaluate the cleaning process and carefully monitor its progress safeguarding against any damage [2].

This paper is a synthesis of a broad study regarding the behaviour of the collagenous artefacts subjected to laser cleaning [3]. All the samples in this complex study are new ones, crafted using traditional formulas and techniques in order to be more appropriate to the collagenous artefacts. Important cases have been validated on the basis of morphological evaluation of a sequence of fresh leather samples, cross-examined using macroscopic control and aesthetical evaluation techniques that show an

efficient cleaning, as well as microscopic and chemical procedures for control of induced ageing effects. The results prove that with a proper selection of the laser regime, the fibril structure is preserved and no induced ageing is present. Positive results were obtained by NIR that suggest no modification of collagen catena occurs.

The subject under discussion in this paper is focused on the parchment samples.

2. Experimental part

Our experiments were carried out on new parchments produced by ICPI-Leather and Footwear Research Institute- Bucharest- Romania. Processing operations for goat and sheep skins to obtain parchment are simple, only requiring washing, removal of hair and adhering residual flesh, and drying under tension. Washing is performed with Na₂CO₃ and house soap, and dehairing is performed with lime. Dehairing may take 2 days to one week based on the kind of skins and their curing state, environment temperature, and dehairing operation variables.

The parchments were subjected to two types of experiments: one on clean samples and one on artificially soiled samples. The artificial soiling was carried out using natural charcoal that was applied manually, in an uniform manner, on the samples, keeping one area as a clean (before soiling) reference.

The laser cleaning was carried out using a Q-switched YAG:Nd laser working at fundamental wavelength - 1064

nm, and its first harmonic - 532 nm, at a frequency of 2 Hz

using different energy regimes.

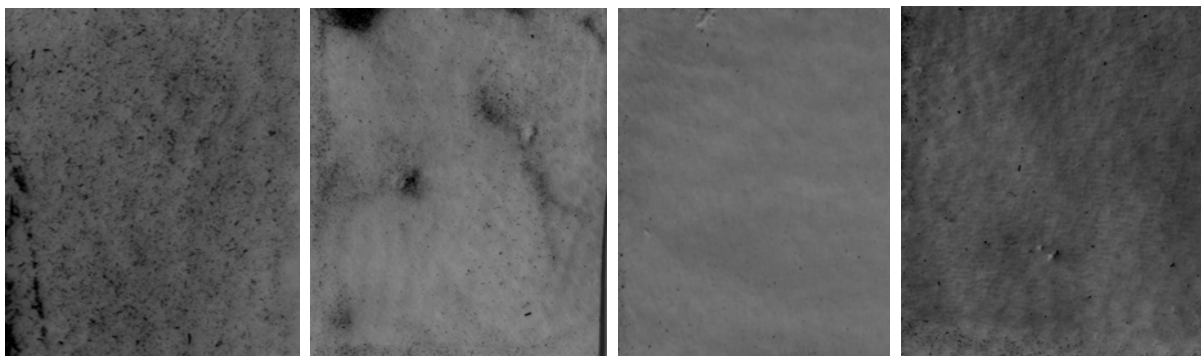


Fig. 1. Extract from visual investigation data base of Kid samples: laser cleaning at 532 nm: dirty, 0.3 mJ/cm², 0.6 J/cm², clean (from left to right).

Following the previous tests made on leather samples corroborated in the first part of this study [3], the parchment samples' analysis was developed on two directions of investigation of the laser cleaning effects:

From the visual assessment and aesthetical point of view:

- *Colorimetry* – the CIEL*a*b* colour parameters and spectral characteristics allow us to monitor the surfaces' chromatic differences working with the spectral signature of reflected light from the surface.

- *Microscopy* investigations in order to explore the characteristics of the samples' relief - before and after laser cleaning, revealing any deterioration on the surface morphology that may be induced.

Probability of causing induced ageing:

- *Shrinkage temperature* – The micro hot table method (MHT) utilizes the measurement of hydrothermal shrinkage observed when a sample is subjected to a controlled temperature dynamics [4].

- IR and UV-VIS-NIR spectral characteristics [5,6].

3. Results and discussion

3.1 Colorimetric investigations

The damage is characterized by different features: weakening, surface powdering, pH change, etc. One feature is the changes in color. Thus, for conservation and restoration purposes it is important to monitor the color change. Many color models have been developed during

the years, The International Committee on Colorimetry (CIE) defined certain color models as CIE X,Y,Z, CIE L*a*b*, CIE L*u*v*, CIE L*C*H* (Lightness, chroma, Hue), and CIE HVC (Hue, Value, Chroma). The most used color models are the perceptually uniform models CIE L*a*b* and CIE L*C*H* because of their features as humans vision and the underling both the color components (L* - color lightness, color coordinates: $\pm a^*$ – red/green and $\pm b^*$ – yellow/blue) and the color difference (ΔE^*_{ab}) [7].

In this paper one of the common color models CIE L*a*b* has been applied, using a portable colorimeter, in order to quantify the color changes that are present in relation to the reference clean and not irradiated parchment. Additional working on goat parchment – laser cleaned by 1064 nm wavelength.

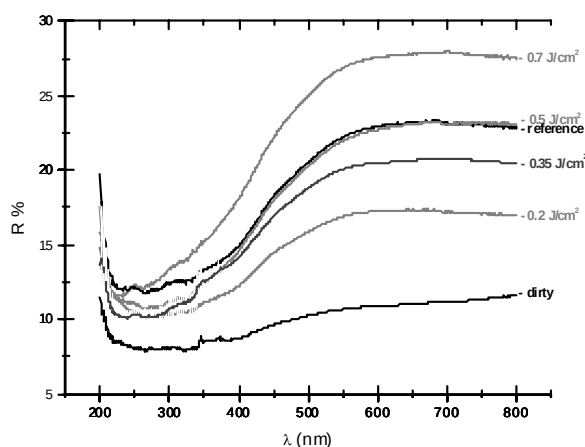


Fig. 2. UV-VIS spectrum of the goat parchment cleaned with laser at 1064 nm wavelength.

Table 1. Colorimetric parameters (CIE $L^*a^*b^*$ color system) for the goat parchment cleaned with 1064 nm wavelength.

clean	0,2 J/cm ²	0,35 J/cm ²	0,5 J/cm ²	0,7 J/cm ²	dirty
$L^* = 51.75$	$L^* = 58.67$	$L^* = 54.11$	$L^* = 53.86$	$L^* = 48.00$	$L^* = 39.02$
$a^* = -1.23$	$a^* = -1.43$	$a^* = -1.12$	$a^* = -1.05$	$a^* = -1.01$	$a^* = -0.41$
$b^* = 5.94$	$b^* = 7.33$	$b^* = 7.18$	$b^* = 7.33$	$b^* = 5.22$	$b^* = 3.02$
	$dL^* = 6.92$	$dL^* = 2.36$	$dL^* = 2.11$	$dL^* = -3.76$	$dL^* = -12.73$
	$da^* = -0.21$	$da^* = 0.11$	$da^* = 0.17$	$da^* = 0.21$	$da^* = 0.81$
	$db^* = 1.39$	$db^* = 1.23$	$db^* = 1.39$	$db^* = -0.72$	$db^* = -2.92$
	$dE^*_{ab} = 7.06$	$dE^*_{ab} = 2.66$	$dE^*_{ab} = 2.53$	$dE^*_{ab} = 3.83$	$dE^*_{ab} = 13.09$

Table 2. Colorimetric parameters (CIE $L^*a^*b^*$ color system) for the goat parchment cleaned with 532 nm wavelength.

clean	0,3 J/cm ²	0,4 J/cm ²	0,6 J/cm ²	0,75 J/cm ²	dirty
$L^* = 51.75$	$L^* = 53.55$	$L^* = 50.80$	$L^* = 47.44$	$L^* = 49.97$	$L^* = 39.02$
$a^* = -1.23$	$a^* = -1.77$	$a^* = -1.77$	$a^* = -1.63$	$a^* = -1.58$	$a^* = -0.41$
$b^* = 5.94$	$b^* = 8.20$	$b^* = 7.64$	$b^* = 6.16$	$b^* = 6.58$	$b^* = 3.02$
	$dL^* = 1.80$	$dL^* = -0.95$	$dL^* = -4.31$	$dL^* = -1.78$	$dL^* = -12.73$
	$da^* = -0.54$	$da^* = -0.55$	$da^* = -0.41$	$da^* = -0.35$	$da^* = 0.81$
	$db^* = 2.26$	$db^* = 1.70$	$db^* = 0.21$	$db^* = 0.64$	$db^* = -2.92$
	$dE^*_{ab} = 2.93$	$dE^*_{ab} = 2.02$	$dE^*_{ab} = 4.34$	$dE^*_{ab} = 1.93$	$dE^*_{ab} = 13.09$

For each parchment sample the color changes were monitored. From the reflectance spectra it can be observed that the reflectance value of the cleaned areas is slightly modified in comparison with the reference sample, the biggest difference being – as expected – the one of the dirty parchment. The difference is decreasing with the increase of the fluency.

The laser cleaning working regime that uses the 1064 nm wavelength has proven to be the optimal one due to the fact that its color index value is the closest to the original (color index difference between the section cleaned at a fluency of 0,5 J/cm² and the sample one: $dE^*_{ab} = 2.53$). As you can conclude from the investigation charts presented above, where the green-red colour axe (a^*) and the blue-yellow axe (b^*) are concerned, the colour fluctuations are small (under 0.5 %).

Goat parchment –cleaned by laser at 532 nm wavelength.

The goat parchment was investigated before and after cleaning at various irradiation wavelength. Fig. 3 shows the results.

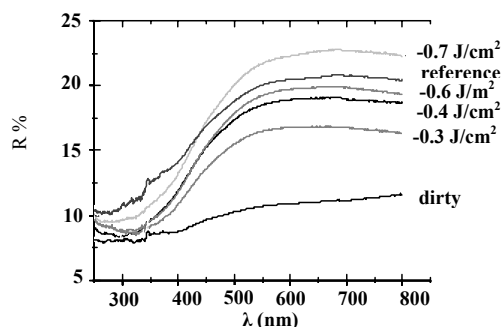


Fig. 3. UV-VIS spectrum of the goat parchment cleaned with laser at 532 nm wavelength.

3.2 Optical microscopy investigations

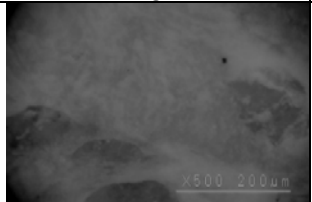
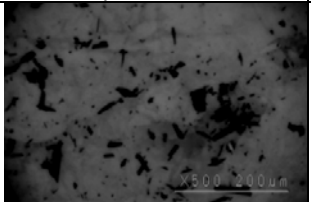
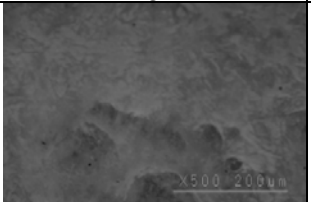
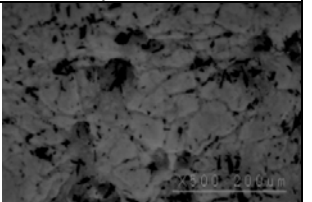
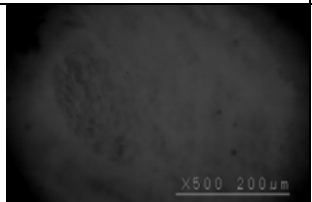
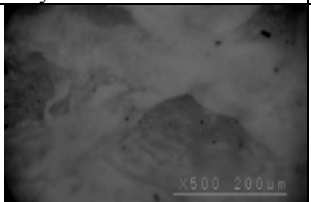
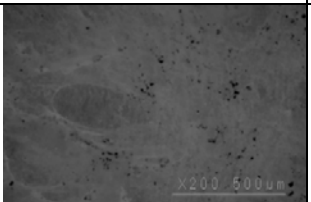
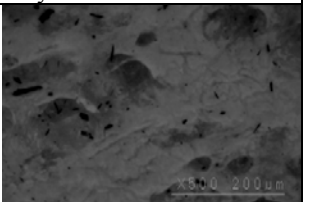
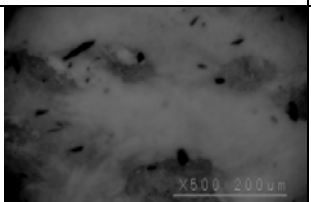
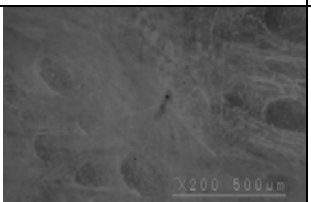
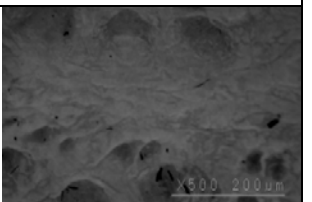
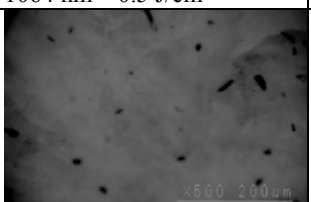
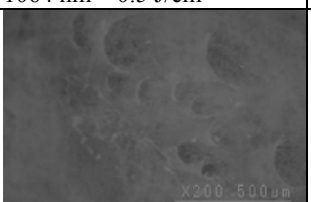
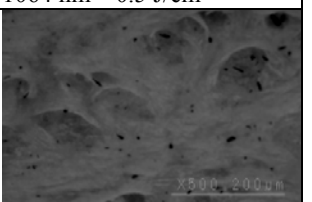
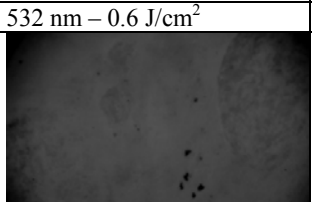
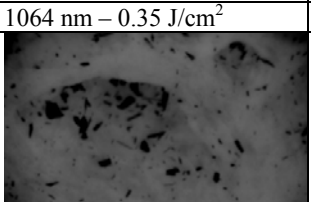
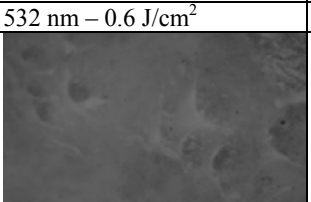
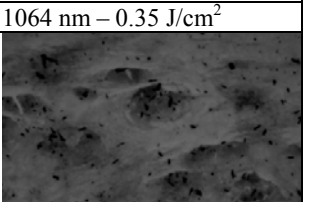
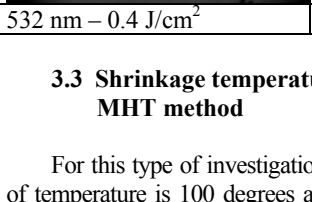
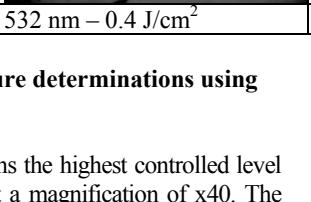
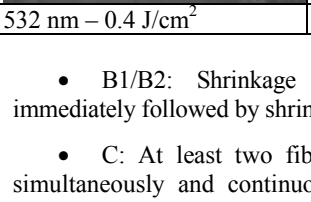
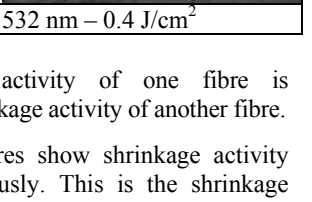
Digital imaging offers a world of opportunities for the microscopist, providing an easy-to-use image acquisition system that enables easy image storage, manipulation and management, being increasingly applied to image capture for microscopy - an area that demands high resolution, color fidelity and careful management of, often, limited light conditions.

Thus, the optical microscopy investigations were accomplished using a portable digital microscope DG-3 that has three standard lens with a magnification of 30x, 50x and 1000x and three high resolution lens with a magnification of 200x, 500x and 1000x. The microscope has a LCD screen incorporated for an appropriate visualization of the image and it comes with a x-y stand and a flexible stand, that allow us to take accurate non-contact, non-invasive microscopic images (with a resolution of 2.1 MPixels) on site, without interfering in any way with the investigated artefact.

From the optical microscopy point of view the laser cleaning didn't induce any morphology changes on the irradiated material and it followed closely the surface relief. The best removal of the impurities was obtained using the 1064 wavelength at 0.5 J/cm².

We present in table 3.3 the results for the goat parchment, at 200× and 500× magnifications.

Table 3. Optical microscopy investigations for the goat parchment cleaned with 1064 and 532 nm wavelengths.

Goat – 500X magnification		Goat – 200X magnification	
Without soiling	Artificially soiled	Without soiling	Artificially soiled
			
reference	dirty	reference	dirty
			
1064 nm – 0.7 J/cm ²	1064 nm – 0.7 J/cm ²	1064 nm – 0.7 J/cm ²	1064 nm – 0.7 J/cm ²
			
1064 nm – 0.5 J/cm ²	1064 nm – 0.5 J/cm ²	1064 nm – 0.5 J/cm ²	1064 nm – 0.5 J/cm ²
			
532 nm – 0.6 J/cm ²	1064 nm – 0.35 J/cm ²	532 nm – 0.6 J/cm ²	1064 nm – 0.35 J/cm ²
			
532 nm – 0.4 J/cm ²	532 nm – 0.4 J/cm ²	532 nm – 0.4 J/cm ²	532 nm – 0.4 J/cm ²
			

3.3 Shrinkage temperature determinations using MHT method

For this type of investigations the highest controlled level of temperature is 100 degrees at a magnification of x40. The shrinkage of the fibres is described in three temperature intervals, as follows:

- A1/A2: Distinct shrinkage activity occurs in individual fibres.

- B1/B2: Shrinkage activity of one fibre is immediately followed by shrinkage activity of another fibre.

- C: At least two fibres show shrinkage activity simultaneously and continuously. This is the shrinkage temperature TS.

The shrinkage activity observed as a function of temperature for fibre sample undergoes the following changes:

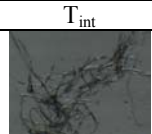
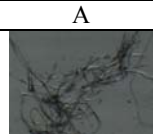
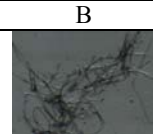
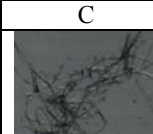
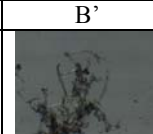
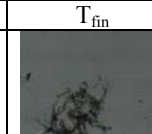
no activity ► A1 ► B1 ► C ► B2 ► A2 ► complete shrinkage

Table 4. Shrinkage activity investigation chart for Kid parchments.

Kid Type A and B– artificially soiled with charcoal								
Sample	Laser Regime - λ and fluency-	T _{in} (°C)	A (°C)	B (°C)	C (°C)	A ₁ (°C)	B ₁ (°C)	T _{end} (°C)
Ka1	1064nm 0.7 J/cm ²	24.5	54.9	61.0	71.5	72.8	74.9	78.4
Ka2	1064nm 0.5 J/cm ²	22.3	55.3	62.1	68.3	71.5	72.3	75.5
Ka3	532 nm 0.6 J/cm ²	24.5	63.2	65.0	68.5	72.5	75.8	80.4
Ka4	532 nm 0.4 J/cm ²	23.7	64.5	66.4	69.9	76.0	77.3	79.6
Kb	clean	26.8	52.4	65.6	69.0	73.3	74.4	77.3
Kb5	1064nm 0.7 J/cm ²	26.2	64.8	68.0	69.5	73.5	74.1	74.8
Kb6	1064nm 0.5 J/cm ²	26.7	65.2	63.8	65.2	70.5	72.8	74.9
Kb7	532 nm 0.6 J/cm ²	26.1	57.7	59.0	64.8	71.8	73.3	74.9
Kb8	532 nm 0.4 J/cm ²	25.5	57.8	62.4	67.9	70.1	72.8	75.5
Kid - no artificial soiling								
Sample	Laser Regime - λ and fluency-	T _{in} (°C)	A (°C)	B (°C)	C (°C)	A ₁ (°C)	B ₁ (°C)	T _{end} (°C)
K9	clean	22.1	64.3	66.9	69.1	70.1	75.6	76.3
K10	dirty	25.8	63.8	65.9	68.9	70.5	73.2	75.9
K11	1064nm 0.35 J/cm ²	25.1	50.7	68.0	70.4	76.5	77.4	79.1
K12	1064nm 0.5 J/cm ²	26.9	58.9	62.3	66.8	69.35	72.5	75.8
K13	1064nm 0.7 J/cm ²	25.6	59.7	62.2	67.2	70.1	71.8	73.7
K14	532nm 0.4 J/cm ²	26.7	63.7	65.3	66.8	71.9	73.9	76.1

A typical shrinkage activity is shown in Table 5.

Table 5. Shrinkage temperature activity for sample K₁₁.

T _{int}	A	B	C	B'	A'	T _{fin}
						
25.1 °C	50.7 °C	68.0 °C	70.4 °C	76.5 °C	77.4 °C	79.1 °C

3.4 IR and UV-VIS-NIR investigations

The parchment samples were analyzed in IR and UV-VIS-NIR spectral domains using the following techniques:

- IR transmission (small parts of parchment were embedded in spectrally pure KBr forming tablets)
- ATR – attenuated total reflectance (using IR spectral domain)

- diffuse reflection (using UV-VIS-NIR spectral domain)

3.4.1 ATR

From all the samples comprised in this study there were chosen two for further discussions: Ka1-Ka4 and Kid 9-14 (Table 6).

Table 6. Spectral characteristics in IR domain (transmission) for the Kid parchment samples.

Sample	Sample status	A _I /A _{II}	$\Delta\nu$	A _{OH} /A _I	Laser Cleaning Regime -wavelength and fluency-
Ka1	Artificially soiled with charcoal	1.045	112	1.043	1064nm 0.7 J/cm ²
Ka2		1.060	111	1.025	1064nm 0.5 J/cm ²
Ka3		1.026	111	1.050	532 nm 0.6 J/cm ²
Ka4		1.073	112	1.025	532 nm 0.4 J/cm ²
K9	clean	1.023	111	1.023	clean
K10	dirty	1.052	111	1.000	dirty
K11	No artificial soiling	1.061	111	0.971	1064nm 0.35 J/cm ²
K12		1.055	111	1.034	1064nm 0.5 J/cm ²
K13		1.043	111	1.020	1064nm 0.7 J/cm ²
K14		1.049	112	0.977	532nm 0.4 J/cm ²

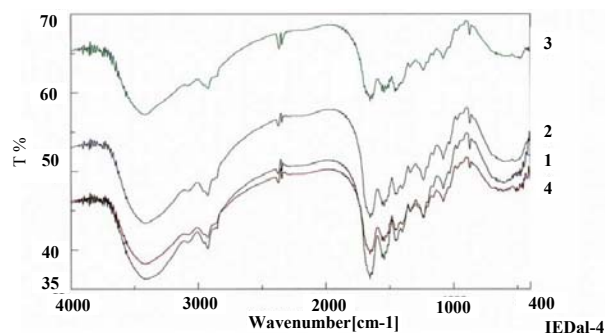


Fig. 4. FT-IR Spectra of Ka1-4 samples.

The data obtained from Ka1 and Ka2 samples are compared with the ones obtained from Kid 9. We notice an increase in the hydrolysis degree, deduced from A_I/A_{II} and A_{OH}/A_I , but the denaturation degree is not affected (Δv). (Fig. 4).

The same aspects were noticed for Ka3 and Ka4, as well as Kid11, 12 and 13.

We must take in consideration the fact that the hydrolysis degree (A_I/A_{II}) of the samples is decreasing once increasing the energy at 1064 nm wavelength.

3.4.2. FT-IR / ATR

ATR Characteristics are described in Table 7.

Table 7. ATR characteristics of the Kid parchment samples.

Sample	Sample status	A_I/A_{II}	Δv	A_{OH}/A_I	$A_{C=O}/A_I$	Laser Cleaning Regime -wavelength and fluency-
Ka1	Artificially soiled with charcoal	0.95	105	0.45	0.05	1064 nm 0.7 J/cm ²
Ka2		1.00	108	0.47	0.03	1064 nm 0.5 J/cm ²
Ka3		0.95	105	0.45	0.08	532 nm 0.6 J/cm ²
Ka4		0.92	105	0.50	0.17	532 nm 0.4 J/cm ²
Kb5		1.25	105	1.00	=	1064 nm 0.7 J/cm ²
Kb6		1.43	105	1.00	0.80	1064 nm 0.5 J/cm ²
Kb7		1.43	105	1.00	0.80	532 nm 0.6 J/cm ²
Kb8		1.43	105	1.00	0.50	532 nm 0.4 J/cm ²
K9	clean	0.93	106	0.48	0.20	clean
K10	dirty	0.88	108	0.50	0.10	dirty
K11	No artificial soiling	0.89	106	0.44	0.05	1064 nm 0.35 J/cm ²
K12		0.97	103	0.43	=	1064 nm 0.5 J/cm ²
K13		0.91	105	0.44	0.03	1064 nm 0.7 J/cm ²
K14		1.00	105	0.44	=	532 nm 0.4 J/cm ²

Considering K9-a sample as etalon the hydrolysis degree (A_I/A_{II} and A_{OH}/A_I) of the samples Ka1-4 is quite close to the etalon, while Kb5-8 samples present a considerable increase with 30 – 50 %. In both this cases the denaturation degree (Δv) is preserved. For the samples K10-14 both of the above mentioned characteristics are similar to the etalon ones.

Using this technique we marked out some oxygenate groups at $1730 \pm 5 \text{ cm}^{-1}$ and $1790 \pm 5 \text{ cm}^{-1}$ that indicate the presence of organic acids and anhydrides as structures formed during the laser irradiation.

The samples Kb5, K12 and K14 did not formed any oxygenate structures. (Figs. 4, 5, 6, 7).

3.4.3 UV-VIS-NIR analysis

UV-VIS-NIR analysis was carried out on Kid samples, with sample K9 as reference.

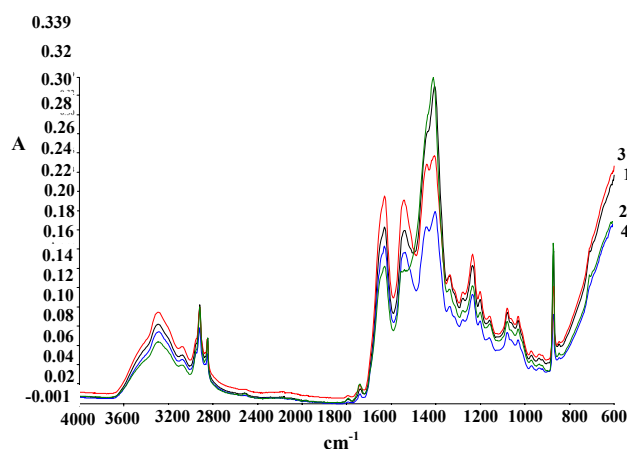


Fig. 5 FT-IR/ATR spectra of Ka1-4 samples.

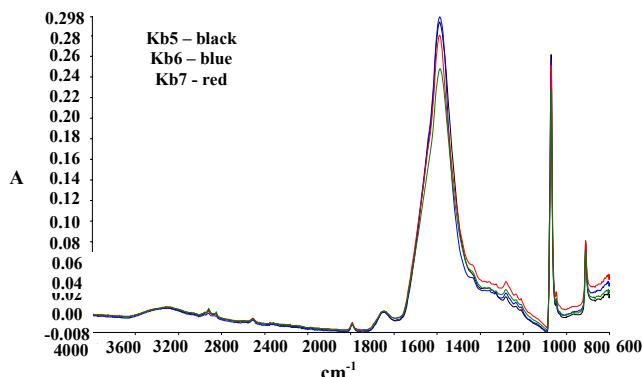


Fig. 6. FT-IR/ATR spectra of Kb5-8 samples.

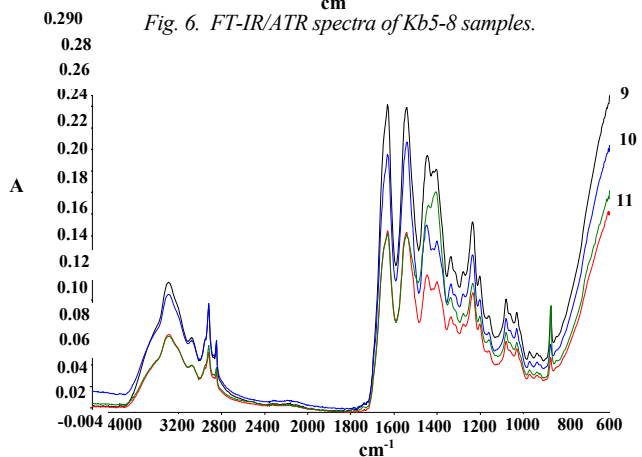


Fig. 7. FT-IR/ATR spectra of K9-12 samples.

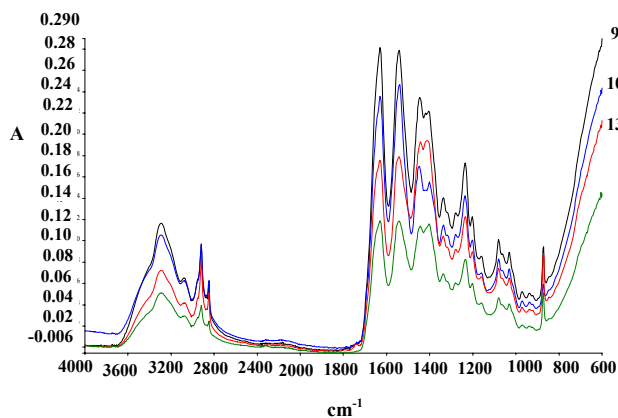


Fig. 8. FT-IR/ATR spectra of K9-10, 13-14 samples.

Table 8. Spectral characteristics in the UV-VIS-NIR range.

Sample	Sample status	UV-VIS (nm)	NIR (nm)	$\Delta\lambda$ NIR (nm)	Laser Cleaning Regime -wavelength and fluency-
Ka1	Artificially soiled with charcoal	250; 270	1492	+12	1064 nm 0.7 J/cm ²
Ka2		254; 280	1486	+10	1064 nm 0.5 J/cm ²
Ka3		255; 280	1502	+26	532 nm 0.6 J/cm ²
Ka4		256; 274	1480	+4	532 nm 0.4 J/cm ²
Kb5		260; -	1502	+26	1064 nm 0.7 J/cm ²
Kb6		260; -	1488	+12	1064 nm 0.5 J/cm ²
Kb7		260; -	1490	+14	532 nm 0.6 J/cm ²
Kb8		262; -	1494	+18	532 nm 0.4 J/cm ²
K9	clean	260; 290	1476	=	clean
K10	dirty	256; 286	1496	+20	dirty
K11	No artificial soiling	260; 284	1496	+20	1064 nm 0.35 J/cm ²
K12		252; 286	1486	+10	1064 nm 0.5 J/cm ²
K13		254; 285	1484	+8	1064 nm 0.7 J/cm ²
K14		256; 286	1488	+12	532 nm 0.4 J/cm ²

The samples Ka1-Ka4 present spectral bands in the same domain as the etalon, slightly moved hipsochrome towards lower wavelengths with 10-30 nm on both transition bands π - π^* and n - π^* . In the NIR spectral domain we noticed that the ν_{OH} band is moved bathochrome towards higher wavelengths with 4-26 nm, fact that implies some associations through the hydrogen links (Fig. 8).

The samples Kb5-Kb8 present only the π - π^* transition given by the aromatic structure placed at the same wavelength as the etalon. In the NIR domain the ν_{OH} band movements are around 12-26 nm fact that proves some strong associations.

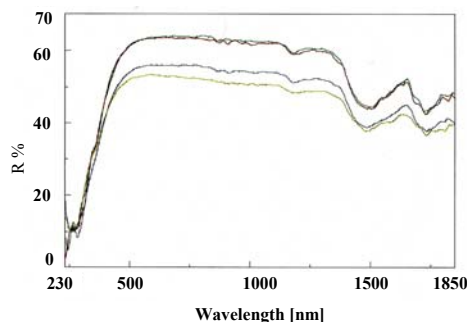


Fig. 9. UV-VIS-NIR spectra of Ka1-4 samples.

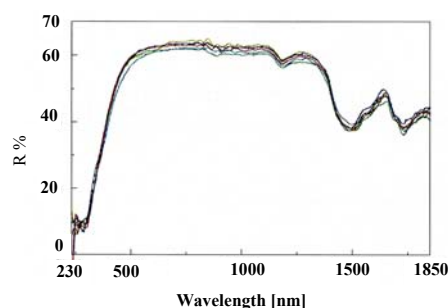


Fig. 10. UV-VIS-NIR spectra of K9-14 samples.

The samples K10-K14 present in UV-VIS hypsochrome movements on both bands, at about 4-8 nm, and on ν_{OH} band bathochrome movements of 8-20 nm. (Fig. 9)

From the UV-VIS-NIR data there were established some correlations between λ_{CONH} at 290 nm (Fig. 10) and $\Delta\lambda_{1476}$ with fluency (Fig. 11).

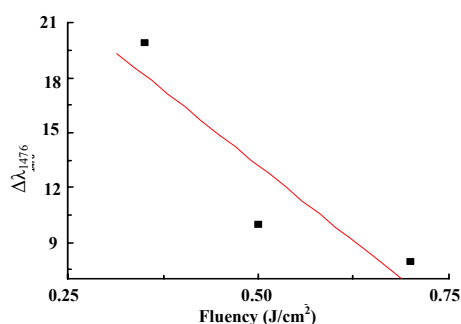


Fig. 11.: $\Delta\lambda_{1476}$ variation with fluency.

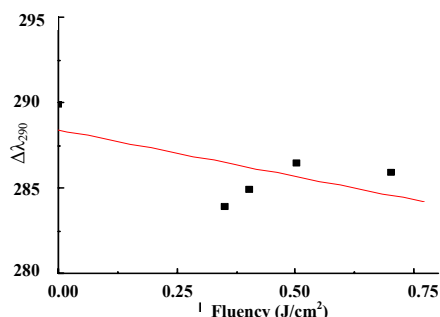


Fig. 12. λ_{290} variation with fluency.

4. Conclusions

Surface monitoring based on chromatic modulation has been carried out for the laser cleaning of different types of leather and parchment, working with the spectral signature of reflected light from the surface. Results show that the spectral parameters derived from the chromatic detection provide not only clear indication of the surface cleanliness and the substrate damage but also useful chromatic information on the surface. The outcome of these experiments consists in an on-line control of laser induced material removal from artworks under restoration.

From the point of view of the shrinkage temperature the laser cleaning technique can be applied safely following the appropriate working regime, because the fibril structure is not affected. Laser cleaning process didn't induce any significant modifications in the shrinkage temperature of the leather fibers, fact that suggests that the geometry of the catena was not affected.

The laser irradiated samples were subjected to IR and UV-VIS-NIR analysis. The modifications induced by the laser radiation are minor concerning the hydrolysis and oxidation levels, without affecting the denaturation level of the investigated samples.

In UV-VIS domain the hypsochrome movements indicate some modifications of the catena that induces transitions at other wavelengths. The bathochrome movements of the ν_{OH} band are attributed to associations of the intermolecular hydrogen links; their strength increases after the laser treatment.

References

- [1] M. Simileanu, R. Rădvan, J. Striber, W. Mărcăneanu, C. Deciu, N. Herăscu, Proc. Simpozionul Patrimoniul cultural din piele și pergament – abordări moderne pentru caracterizare, conservare și/sau restaurare, București, 45-ISBN: 973-87211-9-9, 2006.
- [2] S. Salimbeni, V. Zafirooulos, R. Rădvan, V. Verges-Belmin, W. Kautek, A. Andreoni, G. Sliwinski, M. Castillejo, S. R. Ahmad, Colaiton – CSIC Thematic Network on Cultural Heritage, Newsletter 9, 2 (2005).
- [3] M. Simileanu, M. Giungica, L. Miu, R. Rădvan, J. Optoelectron. Adv. Mater 10(8), 2008.
- [4] Larsen. R, Vest, M. Poulsen, D. V., Kejser U. B., Environment Leather Project. European Commission DG XII, Research Report No. 6, The Royal Danish Academy of Fine Arts, School of Conservation, Copenhagen, 145, 1996.
- [5] M Avram, C. D. Mateescu, Spectroscopia in IR. Aplicatii in chimia organica, Ed. Tehnica, Bucuresti 1966.
- [6] M. Derrick, Annual of the Book and Paper Group, American Institute for Conservation, 10, 1991.
- [7] DIN 174-1976, CIE-Lab Germany.

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