



# PROCEEDINGS



*27th  
International  
Conference  
Ecological  
Truth and  
Environmental  
Research*

**EDITOR**

*Prof. Dr Snežana Šerbula*

18-21 June 2019, Hotel Jezero, Bor Lake, Serbia

**PROCEEDINGS**

**27<sup>th</sup> INTERNATIONAL CONFERENCE**

**ECOLOGICAL TRUTH AND ENVIRONMENTAL RESEARCH – EcoTER'19**

**Editor:**

**Prof. Dr Snežana Šerbula**

*University of Belgrade, Technical Faculty in Bor*

**Technical Editors:**

**MSc Jelena Milosavljević**

*University of Belgrade, Technical Faculty in Bor*

**Asst. Prof. Dr Maja Nujkić**

*University of Belgrade, Technical Faculty in Bor*

**Asst. Prof. Dr Žaklina Tasić**

*University of Belgrade, Technical Faculty in Bor*

**Asst. Prof. Dr Ana Radojević**

*University of Belgrade, Technical Faculty in Bor*

**Publisher:** University of Belgrade, Technical Faculty in Bor

**For the Publisher:** Dean Prof. Dr Nada Štrbac

**Printed:** TERCIJA DOO, Bor, 150 copies

**Year of publication:** 2019

ISBN 978-86-6305-097-6

CIP - Katalogizacija u publikaciji - Narodna biblioteka Srbije, Beograd

502/504(082)(0.034.2)

613(082)(0.034.2)

МЕЂУНАРОДНА конференција Еколошка истина и истраживање животне средине (27 ; 2019 ; Бор)

Proceedings [Elektronski izvor] / 27th International Conference Ecological Truth and Environmental Research - EcoTER'19, 18-21 June 2019, Bor Lake, Serbia ; editor Snežana Šerbula. - Bor : University of Belgrade, Technical faculty, 2019 (Bor : Tercija). - 1 USB fleš memorija ; 9 x 6 cm (u obliku kartice)

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 150. - Bibliografija uz svaki rad.

ISBN 978-86-6305-097-6

а) Животна средина - Заштита - Зборници б) Здравље - Заштита - Зборници  
COBISS.SR-ID 277159692



**27<sup>th</sup> International Conference  
Ecological Truth and Environmental Research 2019**

**is organized by:**

**UNIVERSITY OF BELGRADE, TECHNICAL FACULTY IN  
BOR (SERBIA)**

**Co-organizers of the Conference:**

**University of Banja Luka, Faculty of Technology  
– Banja Luka (B&H)**

**University of Montenegro, Faculty of Metallurgy and Technology  
– Podgorica (Montenegro)**

**University of Zagreb, Faculty of Metallurgy  
– Sisak (Croatia)**

**University of Pristina, Faculty of Technical Sciences  
– Kosovska Mitrovica (Serbia)**

**Association of Young Researchers – Bor (Serbia)**

<b>Maša Knez Hrnčić, S. Šostar Turk, S. Stavbar, Ž. Knez</b>	
REMOVAL OF COMMONLY USED ANTIBIOTICS FROM HOSPITAL WASTEWATER	332
<b>Mirko Gojić, I. Ivanić, T. Holjevac Grgurić, S. Kožuh, O. Beganović, D. Čubela</b>	
MICROSTRUCTURAL PROPERTIES AND DYNAMIC-MECHANICAL BEHAVIOUR OF CuAlMn SHAPE MEMORY ALLOY	337
<b>Vladan Mičić, J. Budinski-Simendić, S. Pavlović, V. Teofilović, A. Aroguz, I. Krakovsky, J. Pavličević</b>	
SUPERCRITICAL FLUIDS AS GREEN SOLVENTS	343
<b>Branislava Lazić, B. Popović, S. Poznanović</b>	
ECOLOGICAL ADVANTAGES OF ORGANIC GROWING COTTON	349
<b>Valentina Simić, M. Šljivić, S. Belošević, M. Milosavljević, I. Karabegović</b>	
OPTIMIZATION OF FLAVONOID EXTRACTION USING MICROWAVE-ASSISTED EXTRACTION AS ECO-FRIENDLY TECHNIQUE	356
<b>Suzana Polić, S. Ristić, B. Radojković, B. Jegdić</b>	
LASER CLEANING OF CORROSION, EFFICIENT AND ENVIRONMENTALLY FRIENDLY METHOD	362
<b>Irma Dervišević, A. Dervišević, J. Galjak, J. Đokić</b>	
RECYCLING VALUABLE AND HAZARDOUS METALS FROM WEEE AND GREEN TECHNOLOGIES	369
<b>Branka Kaluderović, Đ. Čokeša, M. Marković, J. Hranisavljević, V. Mandušić,</b>	
INFLUENCE OF MODIFICATION OF ACTIVE CARBON MATERIAL SURFACE ON ITS ANTIMICROBIAL PROPERTIES	376
<b>Đuro Čokeša, M. Marković, M. Gajić-Kvašček, S. Radmanović, S. Šerbula</b>	
ISOTHERMAL TITRATION CALORIMETRY STUDY OF Cu BINDING TO HUMIC ACIDS FROM TECHNOSOLS ON RECLAIMED Cu POST FLOTATION TAILINGS (BOR, SERBIA)	382
<b>Uroš Stamenković, S. Ivanov, I. Marković, D. Gusković, S. Marjanović</b>	
THE EFFECTS OF DIFFERENT AGING TREATMENTS ON THE MICROHARDNESS AND THERMAL DIFFUSIVITY OF THE EN AW-6060 AND EN AW-6082 ALUMINUM ALLOYS FROM 6000 SERIES	386
<b>Milan Radovanović, V. Nedelkovski, A. Simonović, Ž. Tasić, M. Petrović Mihajlović, M. Antonijević</b>	
ELECTROCHEMICAL BEHAVIOR OF STAINLESS STEEL 316L IN RINGER'S SOLUTION IN THE PRESENCE OF L-TRYPTOPHAN	392
<b>Ana Simonović, I. Veljković, M. Radovanović, Ž. Tasić, M. Petrović Mihajlović, M. Antonijević</b>	
THE INHIBITORY EFFECT OF N-ACETYL-L-LEUCINE ON CORROSION OF BRASS IN SYNTHETIC ACIDIC RAIN SOLUTION	398
<b>Yavor Lukarski, I.V. Atanasov, C.A. Argirov</b>	
PROTECTION OF THE PERSONNEL FROM IRRADIATION DURING PYRO-METALLURGICAL PROCESSING OF METALLIC RADIOACTIVE WASTE ON THE BASE OF MODEL CALCULATIONS	404
<b>Eugene Buško, E. Shavalda</b>	
ASSESSMENT OF THE ENVIRONMENTAL SITUATION IN EUROPEAN COUNTRIES USING NEUTRON ACTIVATION ANALYSIS	412
<b>Irina Kandić, I. Čeliković, A. Kandić, M. Gavrilović, P. Janačković</b>	
ASSESSMENT OF ANNUAL EFFECTIVE DOSE DUE TO INGESTION OF <sup>137</sup> Cs, <sup>40</sup> K AND <sup>210</sup> Pb IN MEDICINAL HERBS FROM SERBIA AND FROM MONTENEGRO	418

## LASER CLEANING OF CORROSION, EFFICIENT AND ENVIRONMENTALLY FRIENDLY METHOD

Suzana Polić<sup>1</sup>, Slavica Ristić<sup>1</sup>, Bojana Radojković<sup>2\*</sup>, Bore Jegdić<sup>2</sup>

<sup>1</sup>Central Institute for Conservation in Belgrade, Belgrade, SERBIA

<sup>2</sup>University of Belgrade, Institute of Chemistry, Technology and Metallurgy, Belgrade, SERBIA

\*[bojana52@yahoo.com](mailto:bojana52@yahoo.com), [bojana.radojkovic@ihtm.bg.ac.rs](mailto:bojana.radojkovic@ihtm.bg.ac.rs)

### Abstract

*In recent years, lasers have been used more and more in different areas of human life, science, industry, medicine, military, agriculture, and show business, protection of environmental and cultural-heritage objects, in the arts and so on. Laser technology has some advantages in many areas over classical methods. This paper presents the results of laser application for cleaning corrosion of metal objects, cooper and brass. The first sample was oxidised cooper plate and the second ashtray made of brass. Nd: YAG laser was used as a source of radiation to clean surface corrosion deposits. Removal of layers from the surface occurs through the process of laser ablation. Three wavelengths were used with different fluences. The cleaning results, i.e. the morphological and chemical changes were investigated by optical microscopy, XRF analysis and colorimetry. The obtained results show that lasers are efficient corrosion cleaning and environmentally friendly method.*

**Keywords:** laser cleaning, metal, corrosion, Nd:YAG laser, cultural heritage

### INTRODUCTION

Corrosion is a problem for all metallic objects. Corrosion is the destruction of metals and alloys due to chemical or electrochemical reaction with the surrounding environment. Electrochemical corrosion is a consequence of electrochemical reactions and is subject to the laws of electrochemical kinetics. The important condition for its appearance is the contact of the metal with the second phase, which has the properties of electrolytes, whereby the metal creates a thin layer with the properties of the electrochemical double layer. This includes all cases of corrosion in a humid atmosphere, as well as corrosion of metals in electrolyte solutions [1].

Pollution of the environment is a major problem facing the modern world that leads to the destruction of eco system, the achievements of civilization and cultural heritage. Interest in the use of laser technologies in this area is caused by the catastrophic degradation of the monuments in recent decades, which is the consequence of the increasing effect of anthropogenic factors. The distressing state of many architectural monuments, sculptures, historical buildings, and museum artefacts and the acceleration of their breakdown processes request the use of new and effective technologies for restoring and preserving such objects. The study and conservation of museum collections request the application of scientific

methodology in the examination, analysis and dating of objects. In all these methods, lasers play an important role [1].

The conventional techniques of metal surface cleaning are based on mechanical or chemical methods which can lead to the substrate being damaged or polluted. There is numerous literatures [1–11] that describes the classic and laser methods and problems accompanying their implementation in cleaning and protection of metals. It can be conclude that lasers can to change some classical, pollutant method with ecological friendly ones in different applications. Lasers cannot prevent pollution or reduce the concentration of harmful substances, but can detect pollutants and determine in which amount are present.

Laser cleaning is of interest due to its great potential for removing contamination or films from different substrates [3]. Lasers have many advantages over conventional techniques. They can be used for contactless and fast surface cleaning and processing (drilling, marking, grooving, cutting and welding) with precisely controlling energy deposition in the material.

Precisely controlled laser cleaning features a unique feature: removes impurities and corrosive products from the surface without damaging the base surface. Laser systems are very efficient, economical, and environmentally friendly compared to existing conventional methods. They do not require chemicals and abrasive materials, or storage for waste disposal. Laser, mobile systems, equipped with different types of lasers can be impulsive or continuous, with high mean power. These can be equipped with an optical cable up to 50 m long, making them suitable for applications such as historical monuments, high voltage pylon cleaning, metal contaminated parts of nuclear plants or facades of large cultural heritage sites. Laser cleaning is applicable in the automotive industry. Lasers can be used for welding, removal of oils and lubricants, cleaning of electronic components and cleaning of tools. Lasers can also be used in the food industry. In the airline industry, laser cleaning is most used in the removal of colours and other coatings from the surface of the aircraft. Lasers can also be used effectively in the selective sintering of different materials.

Many studies [4,5,11] confirm that Nd:YAG lasers ( $l = 1.06 \text{ mm}$ ), with ns pulses, are highly effective in removing inorganic encrustations from artifacts; however, the absorption of laser radiation by bulk material can raise the surface temperature and can cause some changes. Because of that, every investigation of Nd:YAG laser ablation is of great interest for laser application in the cleaning process.

## **MATERIALS AND METHODS**

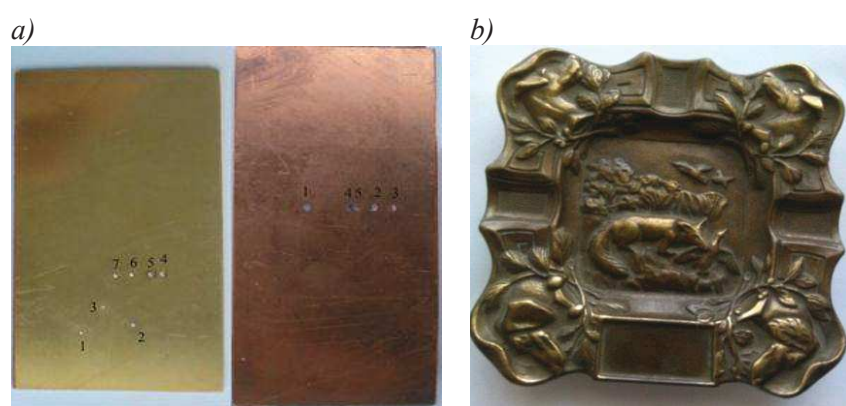
In this paper are presented the results of cooper and brass laser cleaning. The first sample was oxidised cooper plate and the second ashtray made of brass [11].

All experiments were performed in laboratory and normal atmospheric conditions. Nd:YAG laser, Thunder Art Laser, produced by Quanta System (with wavelengths  $\lambda = 1064$  or  $\lambda = 532 \text{ nm}$ , optical pulse duration  $< 8 \text{ ns}$ , and output pulse energy up to  $1000 \text{ mJ}$ ) was used in the presented experiments. The repetition rate is up to  $20 \text{ Hz}$ , with a beam diameter of  $10 \text{ mm}$  and  $70 \%$  fit to Gaussian energy distribution. The lens with focal length of  $150 \text{ mm}$  is used to focus laser beam.

Copper is a metal that has been used for millennia for a wide variety of purposes, and today it is irreplaceable in electronics, computer industry, energy, construction and medicine. Numerous objects of cultural heritage are made of copper or its alloys, bronze and brass. Laser cleaning of copper surfaces is very important with several aspects [1,7].

The experimental parameters are provided in Table 1. The laser cleaned objects are presented in Figure 1. The dimensions of corroded copper and brass plates are 50x30x1 mm and 60x30x2 mm, consequently. The relief ashtray belongs to a private collection, dated to the beginning of the twentieth century.

The results of laser beam-material of the samples were recorded with the optical digital USB microscope with different magnification. Chemical composition was determined by XRF analysis and the colour changes by colorimeter [11].



**Figure 1** a) Oxidized copper and brass plates with laser cleaned zones, b) ashtray

**Table 1** The experimental conditions during laser cleaning of some zones on copper and brass plates and ashtray

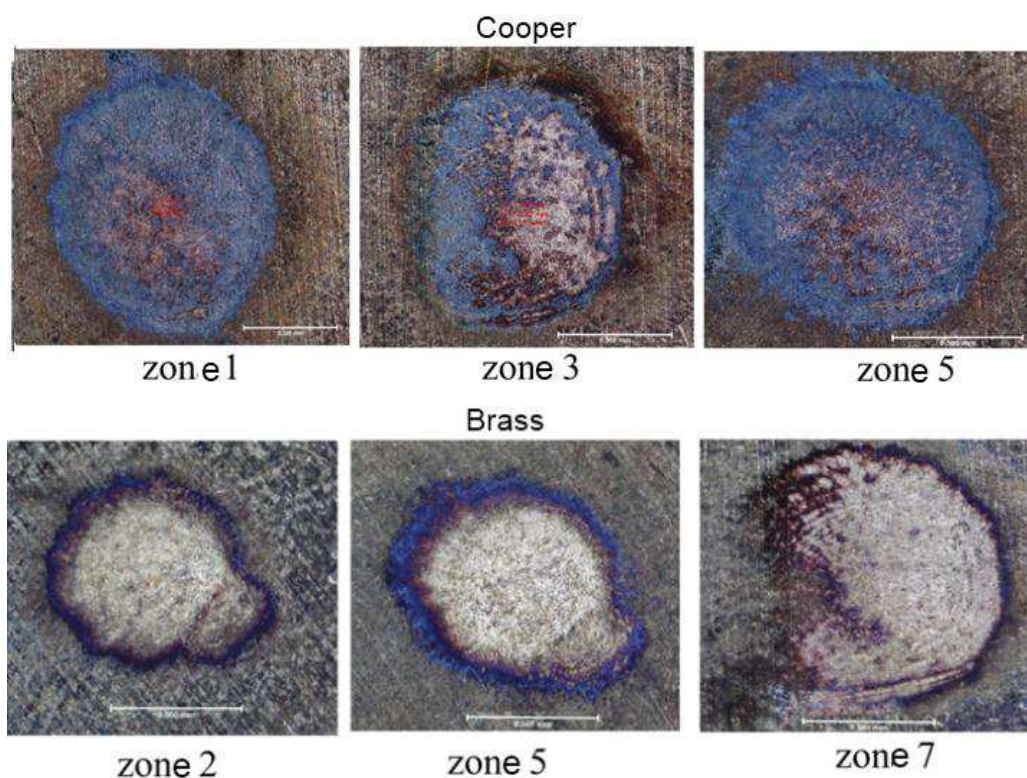
Oxide cooper plate					Ashtray				
Zone number	f, Hz	t, s	E (mJ)	$\lambda$ , nm	Zone number	$\lambda$ , nm	E, mJ	f, Hz	t, s
cooper					1	1064	250	20	5
1	20	5.5	500	1064	2	1064	350	20	5
3	20	4	500	1064	3	1064	450	20	5
5	20	5	200	532	4	1064	600	20	5
brass					5	1064	750		5
2	10	3	500	1064	6	532	375	20	5
5	20	5	500	1064	7	532	375	20	240
7	20	4	200	532	9	1064	600	20	240
					10	355	250	20	240
					11	Mechanically cleaned			

## RESULTS AND DISCUSSION

Surface cleaning, based on laser ablation, is a delicate and irreversible process, followed by many potential complications. It is very important to choose the most suitable laser cleaning methodology and laser parameters in accordance with the material properties. Laser ablation occurs when the laser fluence (pulse energy per unit area) overcomes a critical threshold, which is an intrinsic property of the material structures under irradiation.

The application of laser in cleaning the corrosion layers on metallic threads is a complex phenomenon, depending on characteristics of laser lights and materials. It is based on several processes: absorption of laser energy within a very short period of time (several ns), melting of material in the heating layer depending on the applied energy, and ablation or evaporation of material. Depending on the fluence and quantity of absorbed energy, mechanical expansion waves can be formed, consisting of evaporated material and ambient gas, which also rips off parts of the surface layers and discards them from the irradiated zone. The strength of the expansion wave increases if the sample is damp, and thereby creates conditions for more efficient cleaning of corrosion products. A laser re-melting process is the fundamental process, which occurs in parallel with the cooling of the melted layer.

Microscopic tests, conducted by optical microscopy, allow the study of the threshold of ablation fluence and efficiency of cleaning process. Figure 2 shows some zones on copper and brass plates cleaning with parameters presented in Table 1. The analysis of images show that the corrosion is removed, but some colour changes occur in and around irradiated zones (in HAZ). It can conclude that laser radiation (1064 nm, 8 ns) at fluence levels above 0.6 J/cm<sup>2</sup> causes some melting to copper and brass. Brass appeared to be the most sensitive of the metals tested.



*Figure 2 OM of laser cleaning zones on brass and copper plate*



Figure 3 presents the appearance of the ashtray after partial laser cleaning (rear side) with laser treated zones. Experimental conditions during laser cleaning are given in Table 1. In these studies, the laser parameters have been selected very carefully and they are below the material damage threshold.

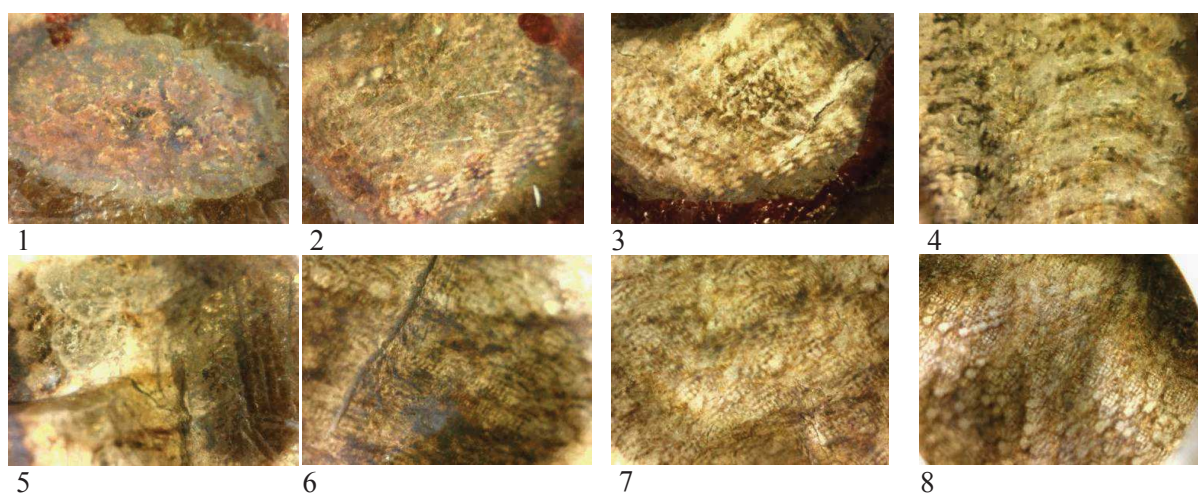
Chemical composition determined by XRF analysis on laser treated and untreated zones, (table 2) points to the fact that there is no coating, there is a thin layer on the surface of the sample that is corroded and which protects the surface against further corrosion. Since the chemical analysis is carried out by XRF method, which cannot detect light elements, it is very likely that on the surface of the ashtray, besides the oxide layer, there is a thin layer of organic materials, which during the laser irradiation leaves dark clues.

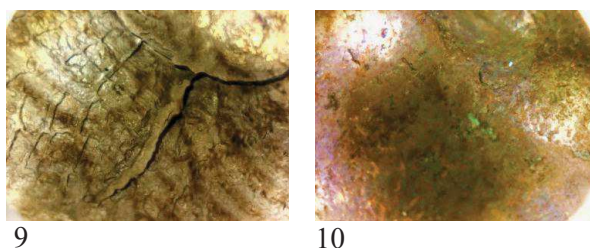
**Table 2** XRF analysis of ashtray [11]

Zone	Concentration % · 10 <sup>-3</sup>													
Elements	Sb	Sn	Ag	Mo	Nb	Pb	Zn	Cu	Ni	Fe	Mn	Cr	V	Ti
Cleaned	17	845	159	5	6	2564	35488	59043	755	580	150	140	159	46
Uncleaned	17	870	159	5	7	2562	33383	59089	754	599	140	164	170	44



**Figure 3** Laser cleaning of ashtray rear side

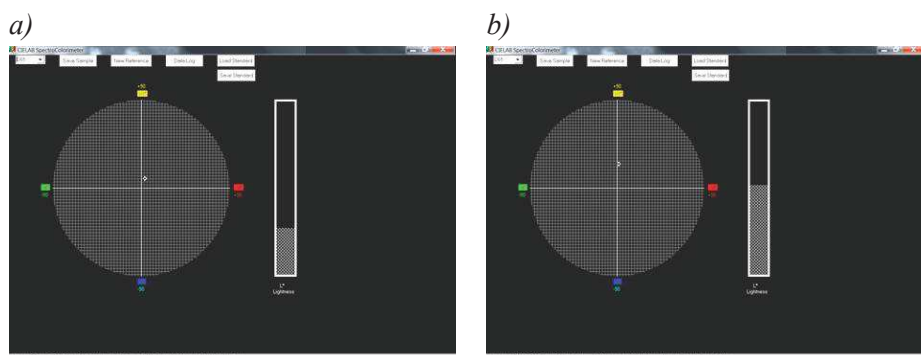




**Figure 4** OM analysis of laser cleaned zones

The images in Figure 4 are made with a USB optical microscope, with a magnification of 40x. An analysis of the images confirmed the inhomogeneity of surfaces that were cleaned by the laser. Around the zone 1-3 appears dark ring, while in the zone cleaned by the scanning laser beam with constant velocity, periodic segments of curved shape are formed.

The results of colorimetric tests for uncleaned surface and for zone 9 are presented in Figure 5. The analysis of the surface colour was based on the L\*a\*b parameters.



**Figure 5** Colorimetry of: a) uncleaned zone, b) zone 9

## CONCLUSION

From the results of the conducted tests, it can be concluded that the use of a Q-switched Nd:YAG laser at 1064 nm and 532 nm is suitable method of cleaning thin corroded layer on copper and brass objects. According the obtained results the ablation threshold fluence for oxidized layers from copper surface is estimated below  $0.5 \text{ mJ/cm}^2$ . Localised surface melting was found to occur at this fluence. The ablated layers evaporate and it is only one by-product of cleaning. No other pollutant in laser ablation. Because of that, laser technology is environmentally friendly and is becoming more and more applicable.

## ACKNOWLEDGEMENT

*The authors are grateful to the Ministry of Culture and Information and Ministry of Education, Science and Technological development of the Republic of Serbia for financial support (TR-34028 and IP 391-00-16/2017-16/38).*

## REFERENCES

- [1] S. Polić-Radovanović, S. Ristić, B. Jegdić, *et al.*, Metodološki i tehnički aspekti primene novih tehnika u zaštiti kulturne baštine, Institut Goša and CIK, Beograd, (2010), ISBN/ISSN: 978-86-86917-12-06 (in Serbian).
- [2] C. Fotakis, D. Angelos, V. Zafiropoulos, *et al.*, Lasers in the Preservation of Cultural Heritage: Principles and Applications, CRC Press, 2005, p. 335.
- [3] Y.S. Koh, Laser Cleaning as a Conservation Technique for Corroded Metal Artifacts, 2005, Doctoral Thesis, Luleå, Sweden, p.114.
- [4] H. Garbacz, E. Fortuna, J. Marczak, *et al.*, Applied Physics A; 100 (2010) 693–701.
- [5] A. Koss, J. Marczak, Application of lasers in conservation of monuments and works of art, 2005, Scientific reports IAICR 1, 50 pages, ISBN: 83-922954-0-4.
- [6] M. Tang, *et al.*, Journal of Laser Micro/Nanoengineering; 6 (1) 2011 6–11.
- [7] B. Radojković, S. Ristić, S. Polić, *et al.*, J. Cult. Herit; 23 (2017) 128–137.
- [8] S. Bashir, H. Vaheed, K. Mahmood, Applied Physics A; 110 (2013) 389–395.
- [9] H. Kadhim, I. Ghazi, A. Hussein, Engineering & Technology Journal; 34 (7) (2016) 1439.
- [10] C. Korenberg, A. Baldwin, Laser Chem; (2006), Article ID 75831, p. 7, doi: 10.1155/2006/75831.
- [11] S. Ristić, B. Radojković, S. Polić, Savremene metode laserskog čišćenja predmeta kulturnog nasleđa, NU IHTM, CIK, Beogradu, 2018, pp. 1–420, ISBN: 978-86-81405-25-3 (in Serbian).

Pavićević, V. 572  
Pavličević, J. 343, 579  
Pavlović, S. 343  
Penavin-Skundric, J. 322  
Petković-Cvetković, J. 16  
Petrov, Đ. 178, 183  
Petrovic, R. 322  
Petrović Mihajlović, M. 392, 398  
Petrović, A. 311, 316  
Petrović, D. 135, 142  
Petrović, Jelena 210, 215  
Petrović, Jovana 178, 183, 497, 504  
Petrović, Maja 195, 284, 296  
Petrović, Marija 210, 215  
Petrović, Milica 78, 84, 205  
Petrović, Miloš 555  
Pilić, B. 585  
Pivić, R. 247  
Polić, S. 362  
Popović, A. 555  
Popović, B.B. 349, 424, 602  
Popović, N. 220  
Poznanović, S.T. 349, 424, 602  
Prodanović, O. 89, 220, 224  
Prodanović, R. 220, 224  
Prokopijević, M. 89, 220, 224  
Purić, M. 311  
Puvača, N. 311, 316

## R

Radaković, N. 28, 565  
Radenković, M. 450  
Radić, J. 284, 296  
Radmanović, S. 382  
Radmilović, Velimir 110  
Radmilović, Vuk 110  
Radnović, D. 233, 240  
Radojević, A. 148, 154, 160  
Radojković, B. 362  
Radotić, K. 89, 301, 305, 551  
Radovanović, Mi. 392, 398  
Radovanović, Mi. 135, 142  
Radović Vučić, M. 78, 84, 205, 535, 540, 545  
Rakanović, M. 322  
Randelović, D. 3  
Ratknić, M. 279, 491  
Ratknić, T. 279, 491  
Razlutski, V. 560  
Ristanović-Ponjavić, I. 456  
Ristić, I. 585  
Ristić, S. 362  
Rončević, S. 115

## S

Sabadoš, K. 296  
Sabovljević, M. 28  
Salmén, L. 551  
Samaržija-Jovanović, S. 608  
Savić, D. 450  
Shavalda, E. 412

Simić, V. 356  
Simonović Radosavljević, J. 89, 224, 301, 551  
Simonović, A. 392, 398  
Sinadinović-Fišer, S. 579  
Sladojević, S. 322  
Slivoski, O. 485  
Smirnov A.I. 189  
Spalović, B. 615, 622  
Spasojević, D. 220, 224  
Sremački, M. 284, 296  
Stajić, B. 565  
Stajić, S. 491  
Stamenković, U. 386  
Stamenović, M. 572, 591, 596  
Stanković, Mihajlo 264, 270  
Stanković, Mira 89, 301  
Stanković, T. 555  
Stanojević, I.M. 445  
Stanojković, J. 28  
Stanojković-Sebić, A. 247  
Stavbar, S. 332  
Stavretović, N. 178, 183, 497, 504  
Stavreva, S. 485  
Stevanić, J. 551  
Stojadinović, S. 135, 142  
Stojanović, S. 450  
Stojanović, T. 555  
Stojčević, B. 459  
Stojković, P. 135, 142

## Š

Šarkoćević, Ž. 459  
Šekularac, G. 279, 491  
Šerbula, S. 148, 154, 160, 382  
Šerović, R. 34  
Šljivić, M.R. 356, 445  
Šoštar Turk, S. 332  
Šoštarčić, T. 215  
Štrbac, D. 195, 228  
Štrbac, G. 195

## T

Tamindžija, D. 233, 240  
Tanasić, J. 585  
Tanasić, Lj. 608  
Tasić, Ž. 392, 398  
Tenodi, S. 115  
Teofilović, V. 343  
Torebekov, O. 64  
Torović, Lj. 328  
Tošić, D. 627  
Trajanović, M. 450  
Tubić, A. 115, 258  
Tubić, B. 172, 560

## U

Umetbayev, R.N. 189  
Ušćumlić, G. 16  
Utelbayeva, A. 64

[eco.tfbor.bg.ac.rs](http://eco.tfbor.bg.ac.rs)



ISBN 978-86-6305-097-6