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Original article

Preliminary investigation on the use of the Q-switched Nd:YAG laser to clean corrosion products on museum embroidered textiles with metallic yarns

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ABSTRACT

The classic methods of cleaning old-fashioned textile museum objects with metallic yarns do not often yield expected results. The use of laser in the conservation of these objects plays an important role as a very efficient and ecologically friendly technique. Conservation and restoration of historical exhibits with metal-textile combinations is becoming ever more complex due to a huge variety of damaging factors. The paper presents the results of the corrosion laser cleaning effects on ethnographic textile with silver coated copper yarns from the holdings of the Ethnographic Museum in Belgrade, using Nd:YAG laser. The testing of the cleaning effects was performed by optical and scanning electron microscopy. The chemical analysis of yarns was done by the EDX and XRD analyses. The parameters for successful and safe cleaning of corrosion products on metallic yarns were determined.

1. Research aims

The paper presents the results of the research on laser application for cleaning corroded metal yarns on embroidered textile artworks. The aim of this work is to determine optimum laser parameters for a successful cleaning of corroded metal yarns without any damage to metal strips and underlying cotton, on a sample of a female shirt from the museum collection. Different laser wavelengths and fluencies were used in dry and wet experimental conditions. Morphological and chemical modifications in the laser-cleaned zones were investigated by optical and scanning electron microscopes, as well as by energy-dispersive (EDX) and X-ray Powder Diffraction (XRD) spectroscopy. The obtained results confirmed that for these samples, which are a combination of two different materials, silvered copper strip and cotton, the application of Nd:YAG lasers with appropriated parameters is a more effective cleaning method than the classic ones. The evaluation of the tested areas can lead to important conclusions and a further laser cleaning of the shirt will be based on the obtained results.

2. Introduction

The deterioration of the museum objects depends on environmental factors such as humidity, temperature, light, pollutants, microorganisms and insects. It induces structural damage, modification of materials, corrosion and agglomeration of pollutants and microorganisms on artworks stored in museum depots or exhibited in galleries.

Numerous research works describe the classic methods implemented in cleaning of metallic yarns in textile museum objects [1,2]. Traditional cleaning methodologies usually apply mechanical removal or chemical reactions, or a combination of these two methods [3]. An ideal cleaning treatment should remove a tarnished layer without affecting either the underlying metal surface or the fabric.

Lasers can controllably and selectively remove undesired layers from surfaces, with high accuracy. Results of laser cleaning depend on a number of parameters related to laser and object surface

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characteristics. The most complicated case is the use of lasers in cleaning items with multi-component structures [4–7].

Laser cleaning is an effective cleaning technique of metal corrosion layers since it provides a high degree of control that allows objects with a considerable amount of surface detail and different materials to be successfully and safely cleaned. There are many investigations of lasers applications in cleaning glass [8], ceramics [9], stone [10,11], easel and wall painting [11,12], metal objects [11,13–15], textile [5–7,16–18], etc. Determination of the most appropriate methodology for successful laser cleaning contains an optimization of laser parameters in accordance with material properties. Also, a good knowledge about the ablation mechanism that occurs is required [1,16,17,19].

Nd:YAG lasers are highly effective in conservation of artworks, as it has been confirmed in numerous tests. Siano et al. [11] present a state-of-the-art, innovation and a new perspective application of Nd:YAG lasers in cleaning different artworks. The cleaning of dirty, corroded surfaces of two copper alloys archaeological objects with Nd:YAG laser, with a wavelength of $\lambda = 1064$ nm and a laser pulse of 120 ns, is presented in [13]. The most complicated implementation of laser in cleaning objects with multi-component compositions such as a metal and textile combination is given in [1,5–7,16,19,20].

Abdel-Kareem et al. [16] used the Nd:YAG laser radiation of a wavelength of 532 nm for cleaning some corroded copper thread samples with cotton fibre core. Nd:YAG lasers influence on silver and copper plates and silk bands as on real artefacts (satin with tarnished silver yarns and corroded silvered copper yarns) were investigated in the study of Degrigny et al. [1]. The Nd:YAG laser used in this study had high fluence but a lower puls frequency in comparison with the tests presented here. Also, their experiments were conducted in the helium atmosphere. The laser cleaning of yarns in museum textiles, consisting of a silver ribbon wrapped around a group of silk fibres, was reported in [5–7,19]. The investigation of Elnaggar et al. [6] used picosecond laser scanning pulses (1064 nm) for the removal of tarnish from the surface of silvered metal yarns. Unlike previous research, in the study the results of which are analysed here, the sample was made of cotton embroidered with silver-coated copper ribbon wrapped around a group of cotton fibres. Also, the nanosecond pulse regime was used for irradiation. Although there are certain published results, this domain has not been sufficiently researched because every object is a problem that requires a study and comprehensive research before cleaning is attempted.

This paper shows the results of the research conducted with the aim of determining the optimum parameters in the cleaning process of the corrosion product on a female shirt from Donja Brnjica, Kosovo and Metohija, Serbia. The shirt was handmade, in the early twentieth century and it represents a part of a Serbian national wedding costume. A very small number of similar specimens are preserved.

The results obtained by using Nd:YAG laser, were analysed by an optical microscope and a scanning electron microscope (SEM) with the EDX and XRD analyses.

3. Degradation of embroidered textile artworks

In embroidered textile objects, various metal yarns can be found. The thickness of precious metal coating is measured in microns [21]. The corrosion processes can occur under external, mechanical, chemical and biological influences [22,23].

Common corrosion products, generated in a reaction of copper and its alloys with the environment, are copper oxides, basic copper sulphates, copper chloride and basic copper carbonates. Some corrosion products protect the underlying metal from further corrosion. However, copper chloride cleaning is necessary with a view to artworks stabilization, and possible further conservation procedures.

Silver objects can form a thin patina, depending on the aggressiveness of the environment [24]. Silver is particularly attacked by sulphide gases. Silver sulphide usually appears as a black layer of corrosion on silver museum objects and this kind of corrosion is known as tarnish.

4. Sample description

The Ethnographic Museum in Belgrade stores a great number of textile objects which are part of the world cultural heritage and it puts significant efforts to provide the necessary conditions for preventive protection [4]. In spite of all efforts, in the early nineties of the past century, changes as dark and brittle yarns were observed on several objects with metallic yarn embroidery. With time, this phenomenon became visible on a growing number of exhibits.

The studied shirt, dated from 1914, was made of cotton embroidered with cotton and silver-coated copper yarns. The photos of the shirt are shown in Fig. 1 (a and b were recorded in 1964 and c–e in 2013). Silver-coated copper sequins were fixed with glass beads using a cotton thread. It is also decorated with glass beads, strung on a cotton thread (Fig. 1b). The parts with the metallic yarn embroidery are sewn between the pieces of tulle [4].

Donja Brnjica is a village five kilometers north of Priština. In the whole Serbian cultural heritage, so consequently on Kosovo and Metohija, embroidery is a very important method of decorating textile items. With industrialization which at that time took place in Serbia, embroidery techniques were improved. Wedding shirts were specially decorated with gilded and silver yarns.

The shirt embroidery was in an excellent condition in 1964 (Fig. 1a and b). The shirt was kept in a storeroom treated with different pesticides. Mothballs based on paradihlorbenzol were placed in textiles depots from 1968 to 1984, after the regular, annual air ventilation. From 1984 to 1999, the pest control of the depots was done with fumigants such as Nuvan 7 and phosphine. Afterwards protection was carried out by the herbal strewing solution (tansy). During the years, defects caused by corrosion have appeared and have slowly led to the destruction of the embroidered parts.

The tests of corrosion causes began in 2000. The measurement on the metal yarns showed that the pH value was 3.5, which means that the reaction was substantially acidic. The damaged silver samples, tested by emission spectroscopy, showed significant presence of phosphorus (9%).

Metal phosphide tablets, used in depot fumigation, develop phosphine. In the atmosphere, which has a higher oxygen content, phosphine tends to transform into a stable form – phosphoric acid. Phosphine reacts with precious metals and causes corrosion. With the increase of temperature and humidity, the reaction rate increases. Also, condensation of water vapor over abrasive and hygroscopic dust particles on the surface of museum objects can stimulate the growth of microbes and accelerate corrosion.

The cleaning of the metallic yarn on the shirt was performed by applying a classic method: it was treated with a 75% aqueous solution of phosphoric acid (H_3PO_4). After washing with distilled water, neutralization was carried out in a sodium bicarbonate, 1% aqueous solution, followed by another rinsing with distilled water. Some parts of the embroidery were protected with paraloid B82. During the cleaning process, the embroidery began to fall off from the fabric (Fig. 1e). Detail tests were performed in order to determine the effect of chemicals on the textile. These tests included: visual analysis of the samples, determination of the raw material composition, effects of the chemical treatment of the samples, calculation of the concentration of the acid and neutralizer regarding to pH values, as well as testing shrinkage and strength [4].

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