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Engineering and Innovative Processes and Techniques for the Conservation of Cultural Heritage

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Abstract In this paper, engineering and innovative processes and techniques for the conservation of cultural heritage are presented. In particular, the ancient artifacts are coated with polymeric mixtures diluted in water, treated by acoustic levitation, displayed on a FT-IR microscope, heated in a specific glass bell and lastly analyzed by InfraRed (IR) spectroscopy. On one side, the innovation of the acoustic levitation permits a better penetration of the polymeric solution during the treatment of the sample, on the other to follow the polymeric drying process in the function of time. Furthermore, IR spectroscopy technique is employed to understand what is happening inside the artifact and to evaluate the thermal response. This new engineering approach for the conservation and preservation of cultural heritage has been shown to be rather valid and has been reported an application example on wood.

Keywords Acoustic Levitation, InfraRed Spectroscopy, Polymeric Mixtures, Cultural Heritage Conservation.

Introduction

Nowadays, different interdisciplinary studies, processes and innovative techniques are more and more employed to conserve and preserve ancient artifacts belonging to the cultural heritage. In the specific case of wooden artifacts, such as dry wood (sculptures and paintings on wooden panels) or wet wood (e.g. archaeological wood), the physical, chemical and biological effects due to time passes cause the degradation of their technical and decorative features. Therefore, it is understandable, as without appropriate processes and techniques of conservation, protection and preservation, all these findings will meet the ruin until to an irreversible destruction, also caused by the high degree of wood tissue degradation because of the wood destroying fungi and bacteria.

Wooden cultural heritage is an inexhaustible source of information for both historians and researchers of the past, in fact it constitute material evidence of history, so, it is of paramount importance to develop new methods for historic wooden artifact conservation with a wide range of applicability.

Wooden artifacts conservation is an highly complex matter on the borderline of aesthetic, art and science, it is necessary sustaining the physical integrity while retaining the authenticity of findings. In this context, the development of safe and effective methods for cultural heritage conservation is extremely important to provide and to transfer historical knowledge to future generations. The purpose of such research is to develop innovative processes and techniques for wooden findings conservation and preservation.

Since the 1950s, artificial resins have been employed to strengthen and to consolidate the damaged wooden artifacts. If on one hand, they present a large number of advantages, on the other hand, with the passing of time, they exhibit a lot of serious disadvantages, in fact they take way some wood components, that negatively

changes the wood characteristics, weaken the wood structure and make it fragile and very susceptible to destruction. Furthermore, they cause the discoloration and damageof the finishing layers.
Mostly synthetic polymeric solutions are recently employed in archaeological wooden findings conservation and preservation as to strengthen the degraded wood tissue. They penetrate thoroughly into the internal structure of the wood, displacing the natural moisture in the microscopic and lattice like structure of the woo fiber walls by diffusion of the large molecules of the chemical.
It also important to develop innovative techniques to the wood treatment. In this context, acoustic levitation is employed to raise the penetration of the polymeric solution and to follow the polymeric drying process in the function of time.
There are many levitation techniques [1], that can be used to suspend a sample in air, e.g. optical [2,3], electro-magnetic [4–7], electrostatic [8–10], gas-film [11,12], aerodynamic[13–27] and acoustic levitation [28–49].Among these quotes, the last one permits to analyze the hydrogen-bonded systems of biophysical interest, for example aqueous solutions[50–56], disaccharides [57–74], proteins [75–78], polymers [79–127] and polyols [128–134]. For these systems, is extremely important to address the experimental studies to the whole concentration range, starting from highly diluted to highly concentrated solutions. So far a significant experimental material has been accumulated on the properties of polymer solutions diluted in water [81-120], obtained by inelastic light diffusion [53], incoherent neutron dispersion [135–139] etc.
In this paper, engineering and innovative processes and techniques for the conservation of cultural heritage are presented. In particular, the ancient artifacts were coated with polymeric substances diluted in water, treated by acoustic levitation, displayed on a FT-IR microscope, heated in a specific glass bell and lastly analyzed by InfraRed (IR) spectroscopy. By means of IR spectroscopy it is possible to understand what is happening inside the polymerized treated artifact and to evaluate the thermal response. This new engineering approach for the conservation and preservation of cultural heritage has been shown to be rather valid and has been reported an application example on wood.

Materials and Methods

The main purpose of the paper is to develop innovative, original and effective processes and techniques for the conservation of cultural heritage, in particular, historic wooden artifacts, that are very difficult and complicated issue. Therefore all the tasks and methods within the paper were designed and developed to undertake multiple research and activity contributing to reach the envisaged purpose step by step. In this context, engineering and innovative processes and techniques for the conservation of cultural heritage were developed and in figure 1 summarized.

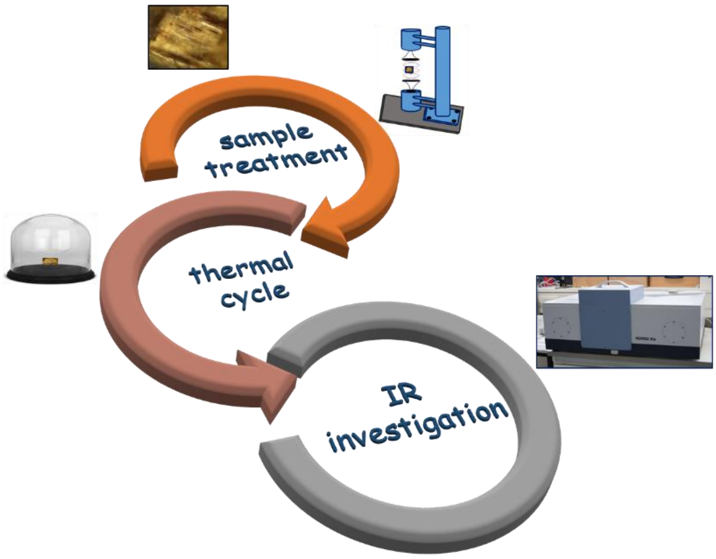


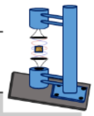
Figure 1: Engineering and innovative step for the conservation of cultural heritage

The first step is the sample treatment: after a bath in the polymeric solution for the sample preparation, the artifact is treated, levitating by means of an acoustic levitator [42]. The action of the levitation guarantees a new approach for sample preparation allowing to obtain high concentrated mixtures starting from highly diluted polymeric solutions diluted in water and to increase the polymer solution penetration within the wood matrix. At the same time, it permits to follow the polymeric drying process as a function of time. The levitation forces that determine the sample shape can be divided into axial forces, main responsible for compensating the gravitational force and radial forces that hold the sample in the pressure node.

The main part of the levitation device is formed by two transducers (or, in general, by an only transducer and a reflector), arranged on a rigid vertical axis of a diameter of 38 mm, in opposite position with a distance of 15 cm, generating two acoustic waves of 22 kHz. These sinusoidal waves produce pressure gradients and interferences that permit the sample levitation in the nodes, which form in the waves. Furthermore, two acoustic absorbing foam disks of a diameter of 50 mm are installed above the transducers to reduce unwanted reflections that cause instabilities in the levitated samples. A capacitive load, varying with the frequency, is represented by an ultrasonic power amplifier, powered by a power supply, formed by a push-pull amplifier and a matching transformer and the power output transistors, powered from a ±40 V rail. The drive signal is send by an acoustic controller circuit that hooks the resonant frequency of the transducers with a phase lock loop and maintains near zero the phase angle between the drive current and the voltage. It also have other important functions, for example, it can enable the control of the drive power, or the relative phase between the transducers, can balance the drive power to the transducers and can modulate the acoustic power.

An oscilloscope guarantees the current circulation within the transducer. The sample is levitated for 40 minutes and can be translated by adjusting the phase between the transducers or squeezed by modulating the acoustic levels with variable frequencies. It is monitored by an infrared video camera, mounted near the sample in levitation, recording video and image that save in a Tough book PC. The table 1 reports the main characteristics of the single axis acoustic levitator. It is rather light (30 Kg) and of small dimensions (30 x 45 x 60 cm), the nominal resonant frequency of the transducer is of 22 kHz, the sound pressure levels of 160 dB and the distance between the two transducers of 150 mm.

Table 1



Single-axis Acoustic Levitator (SAL)	
Frame and levitator system dimensions	30 x 45 x 60 cm
Controller dimensions	60 x 45 x 20 cm
Total weight	30 Kg
Electrical specifications	100/120V 60 Hz, 15A 230 V 50/60 Hz, 15A
Nominal resonant frequency	22 kHz
Sound pressure levels	160 dB
Transducers distance	150 mm

Table 1. Single-axis Acoustic Levitator (SAL) characteristics. The device is rather light (30 Kg) and of small dimensions (30 x 45 x 60 cm), the nominal resonant frequency of the transducer is of 22 kHz, the sound pressure levels of 160 dB and the distance between the two transducers of 150 mm.

The second step is the sample heating, through a specific glass bell in order to make a thermal cycle from to room temperature (20°C) to 350°C, temperature at which the sample burns. After each sample heating, the third step happens: an IR spectrometer is employed to analyze the treated sample and in the specific case, to understand what is happening inside the artifact and to evaluate the thermal response. FTIR Vertex 70 v spectrometer produced by Bruker Optics, used to make an off line collection of the absorption spectra, with a resolution of 4 cm^{-1} and 128 interferograms for each spectrum. The software OPUS was employed to process data and the spectra corrections for atmospheric water background, baseline and area normalization were carried out. Figure 2 shows the internal scheme of the spectrometer.

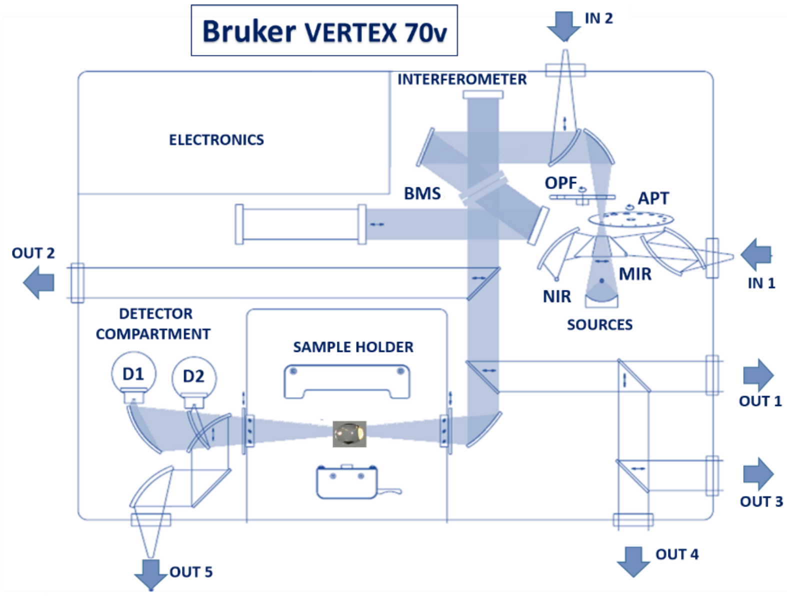


Figure 2: Internal scheme of Bruker VERTEX 70v IR spectrometer

Results and Discussion

The results obtained for acoustically levitated polymeric aqueous solution at atmospheric pressure, used for the treatment of the ancient wooden artifacts and those obtained for the levitated and heated wooden samples with the respective analysis are reported.

In particular, the figure 3 reports the IR spectra of levitated polymeric aqueous solutions at T=25°C for the concentration values ϕ = 0.50 as a function of time, i.e. 0 min, 5 min, 15 min, 30 min and 45 min.

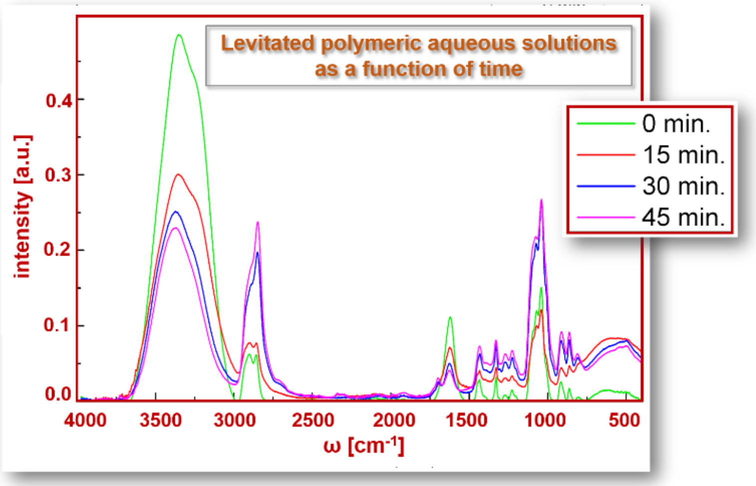


Figure 3: IR spectra of acoustically levitated polymeric aqueous solutions as a function of time (0, 15, 30 and 45 minutes)

The mid-infrared spectrum can be divided into four regions between 4000 and 400 cm^{-1}:

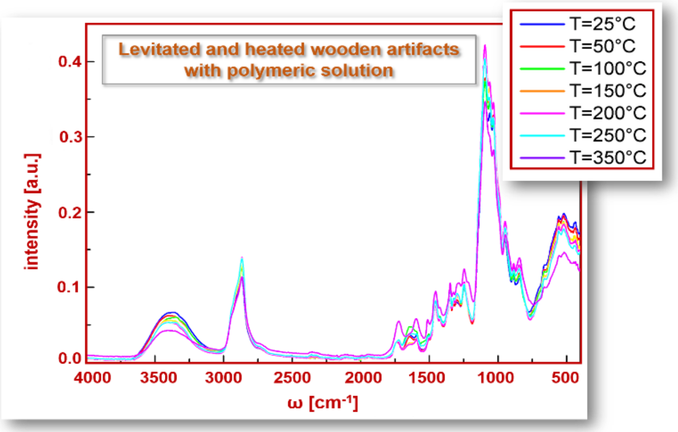
- 4000÷2500 cm^{-1}= X–H stretching region;
- 2500÷2000 cm^{-1}= the triple-bond region;
- 2000÷1500 cm^{-1}=the double-bond region;
- 1500÷400 cm^{-1} = the fingerprint region.

In this paper, the X-H stretching region was explored for polymeric aqueous solutions and has been reported that at concentrations range of 50%, focusing the attention on O-H/C-H stretching.

The X–H stretching region is characterized by fundamental vibrations, usually due to O–H, N–H and C–H stretching. O-H stretching produces a broad band that occurs between 3700 and 3600 cm^{-1}, N-H stretching is generally observed in the range 3400÷3300 cm^{-1}. This absorption is generally much sharper than O–H stretching and may, therefore, be differentiated. The C–H stretching bands from aliphatic compounds occur in the range 3000–2850 cm^{-1}. If the C–H bond is adjacent to a double bond or aromatic ring, the C–H stretching wavenumber increases and absorbs between 3100 and 3000 cm^{-1}.

From the IR spectrum is possible to see like the polymeric solution lost water as a function of time.

Figure 4, on the left, shows the IR spectra of wooden samples treated with acoustically levitated polymeric solutions diluted in water and heated at different temperatures, i.e. 25, 50, 100, 150, 200, 250 and 350°C and Figure 5, on the right, reports the ratio of the OH/CH area as a function of the temperature, from to the room temperature (25°C) to 350°C.



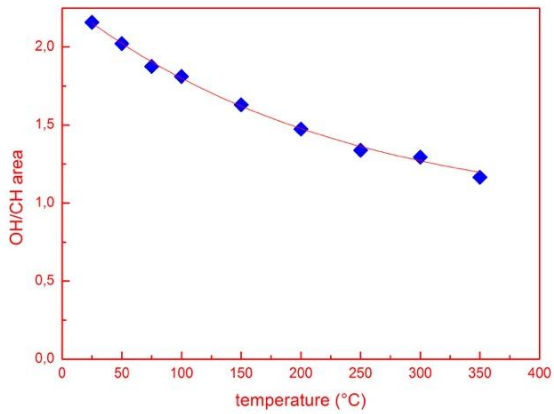


Figure 4: On the left, IR spectra of wooden samples treated with acoustically levitated polymeric solutions diluted in water and heated at different temperatures (25, 50, 100, 150, 200, 250 and 350°C); on the right, the ratio of OH/CH area as a function of the temperature

From this analysis emerges that the ratio of OH/CH contribution decreases at the increasing of the temperature until to reach a plateau about 350°C. This finding suggests that the treatment with PEG allows a major thermal response.

Conclusion

In conclusion, this paper, engineering and innovative processes and techniques for the conservation of cultural heritage were presented. In particular, the ancient artifacts have been coated with polymeric mixtures diluted in water, treated by acoustic levitation, displayed on a FT-IR microscope, heated in a specific glass bell and lastly analyzed by IR spectroscopy.

An applicative example on an ancient wooden artifact was reported. It is shown as, with the acoustic levitation the polymeric solutions penetrate at the bottom of the wood matrix. The main idea behind the innovative solutions is based on technology using acoustically levitated polymeric solutions, integrated in the wood. This new engineering approach for the conservation and preservation of cultural heritage has been shown to be rather valid, that will therefore enable wooden historic findings to keep their shape and spatial form.

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