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Applied neutron tomography in modern archaeology(*)

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Summary. — The use of neutron tomography for archaeometric purposes is quite a new technique. The property of neutron to transmit easily large, dense samples is of great importance in modern archaeology. The three-dimensional visualisation of the inner structure of samples of archaeological interest helps to make suggestions about the technological process of manufacturing or reveals information about the origins of delivering of noble materials used in ancient masterpieces. Another application field in modern archaeology is the non-destructive inspection of the quality of specimen conservation where the neutron tomography allows visualization of impregnation solutions in wood or metal matrices. The high sensibility of neutrons to hydrogen makes it possible to detect organic remains in fossils. All of these advantages make the neutron tomography a unique technique for non-destructive investigation in archaeological sciences.

PACS `81.70.Tx` – Computed tomography.
PACS `87.59.Fm` – Computed tomography (CT).
PACS `28.20.Cz` – Neutron scattering.

1. – Introduction

Neutron tomography has recently found new applications in many different fields like for example in biology, medicine, geology, archaeology and heritage conservation [1-4]. One of the reasons is the fast development in digital image recording and processing, which enables the computation of tomographic reconstructions from high-resolution images at a reasonable timescale. The development of new detectors with better signal-to-noise characteristics and faster read-out electronics has allowed the overcoming of some of

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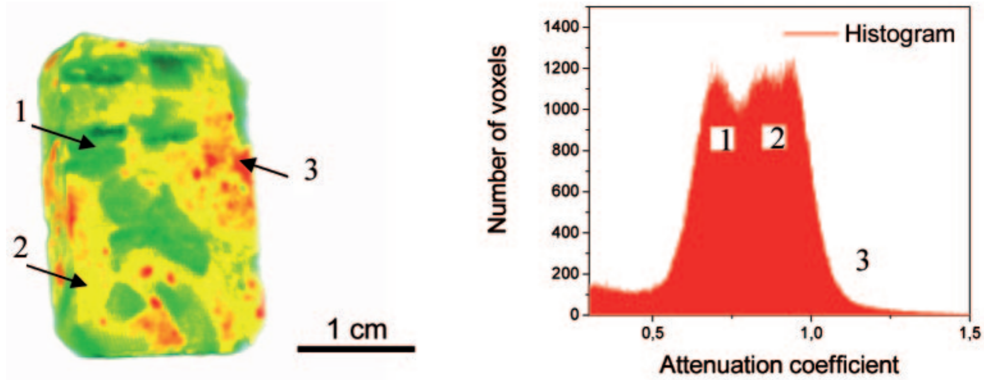

Fig. 1. – Morphological study of a polychromatic marble piece from Villa Adriana (Tivoli, Roma, Italy). The different phases are indicated in the tomographic image as well as in the histogram plot by numbers.

the limitations of conventional neutron radiography and tomography concerning spatial and time resolution [5].

The first results applying neutron tomography for non-destructive investigation on archaeological samples were reported in 1996 [4]. In the following years a growing number of tomographic measurements with neutrons have been performed on such kinds of samples [6, 7]. The aim was always to obtain additional and—compared to other methods—complementary information on valuable archaeological and historical objects without destruction or damage [8].

The ability of neutron radiation to penetrate thick layers of metals and to detect small amounts of hydrogenous materials makes neutron tomography a unique tool for investigating metal samples like historical weapons or jewelry and to characterize the structure of fossils and stone samples as well.

2. – Experimental set-up

The investigations presented below were performed at the neutron tomography instrument V7 (CONRAD) [9]. Different marble pieces of archaeological interest and wood samples after preservation treatment with different aqueous solutions were investigated.

The tomography experiments were performed with an L/D ratio of 250 which gives a spatial resolution of approximately 200 μm. 300 projections of the sample were taken at an angular range of 180 degree. A detector system based on a CCD camera (Andor DW436N-BV, 2048 $\times$ 2048 pixel) coupled to a scintillator screen was used to record the images. The tomography reconstruction was performed by commercial software, OCTOPUS [10], using a backprojection algorithm. The visualization of the data was attained by using commercial rendering software provided by Volume Graphics [11].

3. – Results

3·1. *Investigation of marble samples.* – Among the natural composites, there is a wide variety of stone materials used in buildings, monuments, statues and other objects of archaeological or cultural-heritage interest. Sandstone, limestone, granite und marbles

Table I.

Phase No.	1	2	3
Attenuation coeff. (cm^{-1})	0.50–0.80	0.80–1.10	1.10–1.50
Volume fraction (%)	40	58	2

are the most common stones used for these purposes. Marble may look very different as far as texture, color, mechanical and physical properties are concerned. This is mainly a consequence of the "formation history". Here it is of archaeological interest to link certain types of marbles to the areas and geological formations they have been taken from. Neutron tomography can provide extra quantitative information about the inner composition which can be used to define a kind of grouping of different types of white and polychromatic marbles. An example of this is shown in fig. 1 where quantified neutron tomography data of a polychromatic marble piece from Villa Adriana (Tivoli, Roma, Italy) are presented. The neutron tomographic reconstruction is shown in the left and the histogram plot is given on the right-hand side. Table I lists the computed volume fraction of the different phases presented in the sample.

On the base of this information a morphological classification of a great number of samples can be performed. The idea behind this is to establish a database of samples from different regions and to enable the classification of marble masterpieces by relating them to different morphological groups. The data from the neutron tomography investigation will be related to the data from other research methods, *e.g.*, diffraction or spectroscopy techniques.

3˙2. *Preservation of wood samples*. – The main goal of the study was to show the spatial distribution of the impregnation solution in the wood matrix and to extract quantitative information about the volume fraction of the solution.

Such an example can be seen in fig. 2 where a piece of wood has been preserved by an impregnation solution. The tomography reconstruction shows high contrast between the

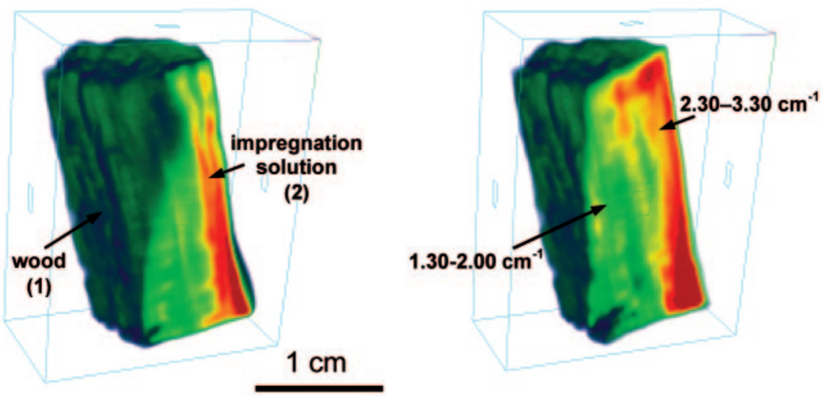

Fig. 2. – Tomographic slices of impregnated wood. The attenuation coefficients for the solution (dark) and the wood (bright) are shown in the right-hand side image.

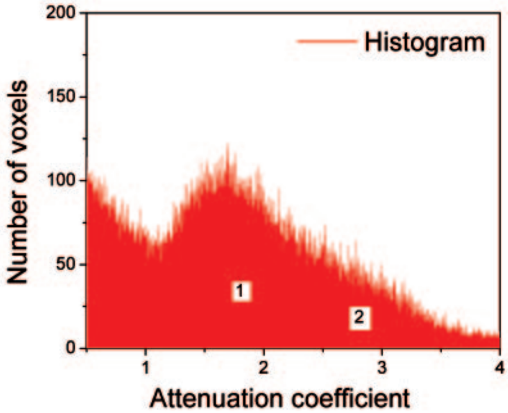

Fig. 3. – Histogram of the attenuation coefficients represented in the sample. The main maximum at 1.70 cm^{-1} corresponds to the wood matrix (1) and the tail 2.30 cm^{-1}–3.30 cm^{-1} is assigned to the impregnation solution (2).

wood and the solution due to the different attenuation coefficients of the two materials for neutrons.

The data were quantified by using the three-dimensional rendering software Volume Graphics Studio [11]. The software allows to extract the histogram of the attenuation coefficients in the sample (see fig. 3) and to calculate the volume fraction of a given material (see fig. 4).

Nine wood samples treated with different impregnation solutions were investigated using the features shown above. Results support previous findings obtained with other techniques [12].

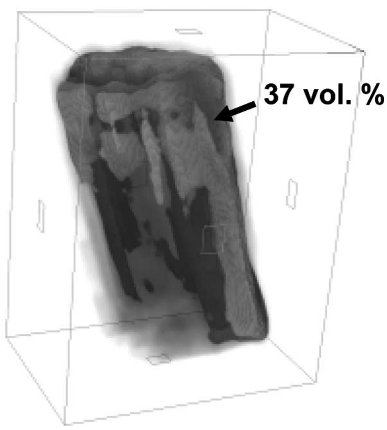

Fig. 4. – The volume fraction of the impregnation solution (2) in the wood sample was calculated to be 37 vol.%.

4. – Conclusion

The possible application of neutron tomography in modern archaeology was demonstrated by two examples of investigation of the morphological structure of stones and of the quantitative characterization of impregnation solution in wood matrixes. The quantitative information obtained from the neutron tomography investigation can be correlated to results from other research methods in order to complete the knowledge about samples of interest. Such kind of interdisciplinary studies are planned for the future.

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