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Computed Tomography with X-rays and Fast Neutrons for Restoration of Wooden Artwork

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Abstract

The objects of this investigation were sculptures taken from a ca. three hundred years old baroque epitaph of a church in Tönning, a town in Northern Germany. Around 1900 it was found in a disastrous state heavily damaged by wood-worm. At that time, the whole artwork was treated with the tar extract carbolineum as a remedy. Nowadays, this substance has been identified as carcinogenic, and its presence can be perceived by its stench and visually at certain spots on the surface where it has penetrated the covering paint.

A gold-painted sculpture of a massive wooden skull was interrogated with X-rays and fast neutrons to investigate the internal distribution of the carbolineum. The X-ray tomography, with its excellent spatial resolution revealed galleries left over from the worm infestation in the outer areas and cracks in the central region. The golden color coating appeared as a thick and dense layer. In comparison the tomography with fast neutrons, though being of lower resolution and yet unresolved artefacts revealed sections of slightly different densities in the bulk of the wood. These differences we attribute to the differences in the distribution of the impregnant in the wood, visible due to its higher hydrogen content making it less transparent for neutrons.

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1. Introduction

The specimens of this study are part of ecclesiastical artwork made of wood that has been neglected for some two centuries and was thus prone to biological degradation. This lasted until restoration became inevitable, but unfortunately with the wrong means that was not evident at that time. So, in the early 20th century the wooden artwork was treated with carbolineum like railway sleepers, with fatal consequences. Carbolineum is a tar oil extract, a carcinogenic substance whose toxicity has been discovered later. As a result, this substance still pollutes the interior atmosphere of the church even today, i.e. a century after the treatment. Moreover, it penetrated through the paint cover to the surface with time, causing an ugly appearance with dark stains. This exactly was the fate of the Epitaph Reyer in the St. Laurentius Church of Tönning, Germany, where this preservative treatment with Carbolineum was undertaken in 1903 (see Figure 1). It is not only an aesthetic aspect to reverse this treatment, but also an environmental and a health issue. Approaches to clean the artwork from this undesired impregnant is not only a chemical problem but also implies the question how it is distributed inside. Gaining an insight non-destructively can be achieved by radiological methods, preferably by computed tomography (CT) for obtaining information on integrity and material density of the interior structures. On this base, one possibly can conclude whether the impregnant is distributed more or less homogeneously or might rather be concentrated in local clusters. This is particularly a methodological challenge that might not be resolved by X-ray technologies alone though they provide better image quality in terms of contrast and in resolving fine structural details. Since carbolineum is an organic substance, it might be expected that local clusters could be identified by neutron radiological methods as they have been applied previously by Osterloh et al. (2008) to identify the distribution of polymerized material in wood. To achieve sufficient penetration through the actual thickness of the interrogated specimens, it was necessary to choose fast neutrons for this purpose. In this study, it will be shown how some material characteristics could be identified with fast neutron CT in conjunction with X-ray CT.



Fig. 1. Epitaph Reyer in the St. Laurentius Church of Tönning, northern Germany.

2. Materials and methods

Some of the sculptures have been removed from the Reyer epitaph and taken as specimens for the decontamination study. One sample is shown here. It consists of a wooden skull model from the basal region in the size of 15 x 10 x 12 cm³ (l x w x h). X-ray and neutron CT studies were performed in order to obtain information

non-destructively about the inside of these samples. The X-ray studies were carried out at the BAM Federal Institute for Materials Research and Testing in Berlin, Germany, while those with fission neutrons in the range of 1.5 to 2 MeV at the NECTAR facility at the Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II) in Garching, Germany, the experiments with neutrons in a higher energy range of average 5.5 MeV and up to 11 MeV were completed at the PTB Physikalisch-Technische Bundesanstalt in Braunschweig, Germany. All the details of the first two sites were recently published by Osterloh et al. (2014) and those of the latter one within this volume (see Weiss-Babay et al). In brief, the X-ray CT encompassed 1000 projections covering 360° and the spatial image was reconstructed with the Feldkamp algorithm (Reinhart, 2008). The X-ray tube voltage was set at 160 keV. The fission neutrons at the FRM II had an average energy of 1.8 MeV and the beam geometry with an L/D of 230 was assumed as a parallel beam so the slice theorem was used for reconstruction here with 180 projections of 5 frames each covering 180°. The accelerator neutrons at the PTB were generated with 11.5 MeV deuterons on a beryllium target so the neutron energy spectrum distribution with an average of 5.5 MeV was well above of that available at the FRM II. The CT was completed with 360 projections consisting of 2 frames covering 360° and a Feldkamp reconstruction algorithm.

3. Results

As the results obtained from the large sculpture of the epitaph have already been reported by Osterloh et al. (2014) this report will focus on the skull model also taken from this epitaph. After an unsuccessful attempt with fission neutrons at the FRM II, it was penetrated successfully only with the fast neutrons at higher energies available at the PTB source. The results will be presented in the sequence of the facilities used as mentioned above starting with the X-ray CT, followed by the attempt to obtain an image with the fission neutrons and the CT obtained with the accelerator neutrons.

3.1. X-ray CT (at BAM)

As shown in Figure 2, the X-ray CT revealed the best result in resolving the structural details with the features of (shrinking) clefts, woodworm galleries within the marginal areas and a dye coating on the outside with a high contrast. The red arrows in this and the following figures will be explained later in 3.4 (cf. Figure 5). However, these images do not reveal any hint about a possible distribution of the carbolineum impregnant.

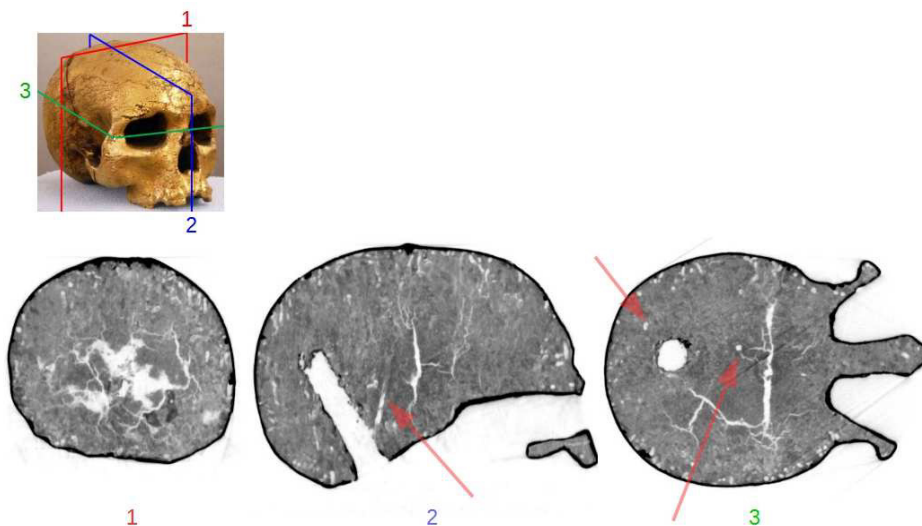


Fig. 2. X-ray CT sections as indicated, in the photo (top left), arrows indicate hole shaped features discussed below (Fig. 5).

3.2. Fission neutron CT (at FRM II)

With the fission neutrons available at the FRM II, it was not possible to obtain images showing internal structural details, as shown in Figure 3. Rather obviously, the energy of the neutrons (around 1.8 MeV) was insufficient to penetrate the specimen in order to generate an informative image. Based on this result we desisted to conduct a full CT in this beam.



Fig. 3. radiographs with fission neutrons around 1.8 MeV.

3.3. Accelerator neutron CT (at PTB)

In difference to the previous result, it was possible to penetrate the object with the neutrons of higher energies of around 5.5 MeV available at the PTB accelerator facility PIAF. The CT results are shown in Figure 4. Though fewer structural details are visible, the density distribution patterns within the CT-slices differ remarkably from those seen in the X-ray CT. Since organic materials are the contrast-giving agents in neutron radiology, these density patterns may reflect a heterogeneous distribution of the impregnant within the volume of the sculpture.

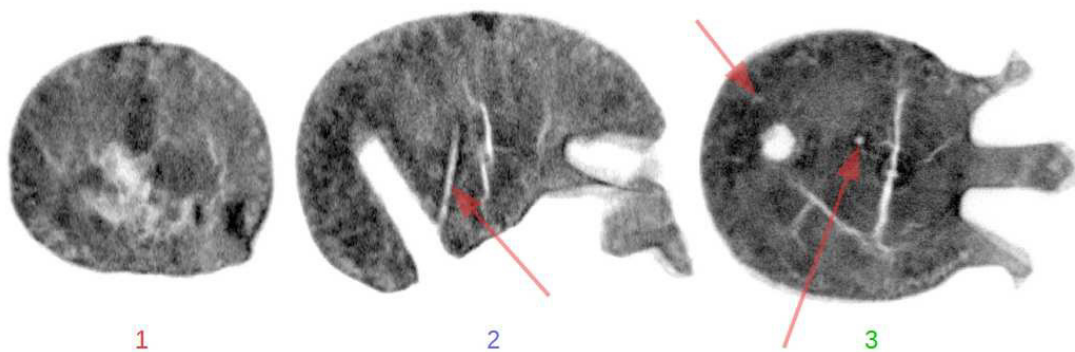


Fig. 4. neutron CT sections as indicated (see Fig. 2) with accelerator neutrons of 5.5 MeV average energy (arrows pointing at hole shaped features).

3.4. Different visibility of a certain detail

There is one detail in the horizontal sections consisting of two nearly equal diameter holes (size ~ 2 mm) marked in the X-ray image. One of them is visible in the neutron CT, the other is not. Following these holes through the adjacent sections revealed a depth of 130 layers equivalent to some 41 mm in the case of the hole visible in both CT scans and of some 20 layers equivalent to 6 $\frac{1}{2}$ mm in the case of the other one that can only be seen clearly in the X-ray CT (see Figure 5 with red arrows). This was confirmed by vertical CT sections through the skull sculpture hitting the long hole in both, the X-ray and the neutron CT as shown in Figures 2 and 4. The hole features in those images are also marked with red arrows. These two holes must be of a different nature.

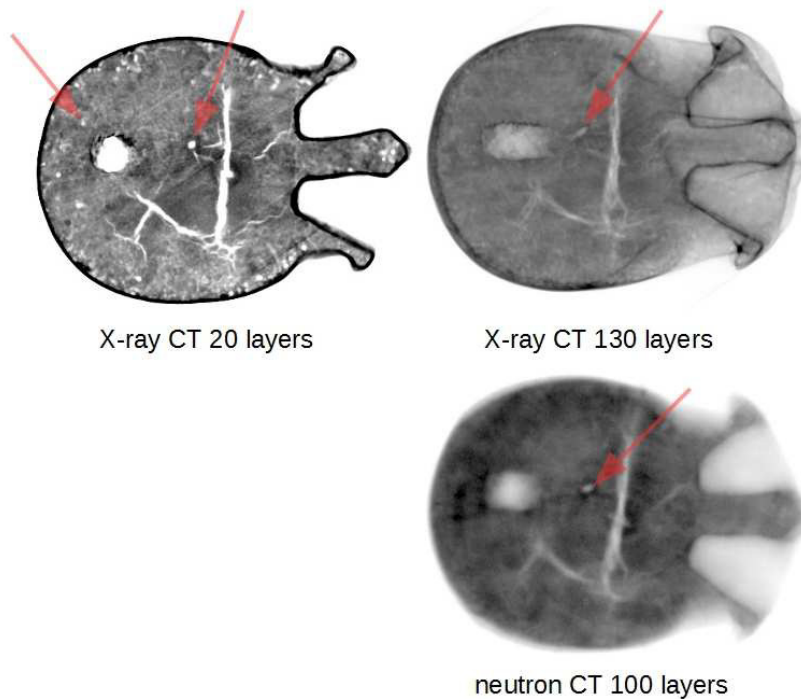


Fig. 5. average of 20 and 130 X-ray CT layers and 100 neutron CT layers tracing the extend of the holes (red arrows as in Fig. 2 and 4).

4. Discussion

The investigated sculpture of the skull was obviously heavily soaked with carbolineum as already indicated by its weight and the characteristic odour emitted. The impregnant was no obstacle when the object was interrogated with X-rays but neutrons in the energy range of up to 2 MeV were not able to penetrate the object sufficiently. So it was necessary to proceed to neutrons of higher energies, i.e. to take advantage of the accelerator facility of the PTB. The heterogeneous density distribution patterns in the resulting CT can be interpreted as local variations of the impregnant content since it is not paralleled in the X-ray CT results. Very obviously, the woodworm galleries clearly visible in the X-ray CT were barely observable, if at all, in the neutron CT whereas a stretched hole of a similar diameter obviously left over from a nail could clearly be seen in both CTs. One explanation could be that the worm galleries must have been loosely stuffed with the debris soaked with carbolineum that was previously left over from the woodworm. However, the carbolineum content could not have been determined quantitatively by absorption measurements due to the lack of suitable standard specimens and adequate calibration procedures. Nevertheless, neutron CT revealed different contrast patterns in the resulting images as compared to

X-ray CT possibly reflecting material peculiarities which remain subject to further research. Unfortunately, it was not possible yet to apply both technologies in one and the same facility to generate images with exactly the same geometry that would have allowed a precise overlay of the images to highlight local material differences. Future work should, therefore, include appropriate hardware extensions wherever possible or at least matching algorithms to compensate for the inevitable geometric differences between various facilities.

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