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Archaeometric investigations on manufacturing processes in ancient cultures with the neutron imaging station DINGO at ANSTO

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Abstract

This paper focuses on recent archaeometric investigations conducted with the neutron imaging station DINGO at ANSTO. The synergic application of non-invasive scientific analytical methods is becoming a common practice in archaeometry and conservation science. Neutron tomography is playing a significant role in expanding the technical limits and investigation capabilities of traditional analytical methods. We discuss advantages and limitations of the technique through the discussion of results obtained from the investigation of artefacts produced by different ancient cultures.

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Keywords: neutron tomography; non-invasive technique; archaeometallurgy

1. Introduction

The study of metal artefacts of archaeological, historical and cultural interest can shed light on the most advanced manufacturing processes developed by different cultures over time. Scientist need to treat them with care and must avoid damage, including the acceleration of any natural ageing process, so that we can pass on the artefacts to future

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generations.

The cultural heritage community is well aware of the benefits of non-invasive scientific methods. This approach has been progressively established as common practice in archaeometry and conservation science. Neutron imaging is playing a significant role in expanding the technical limits and investigation capabilities of standard analytical methods. This is due to its well-known features of high penetration power and different interaction with matter, compared, for example in the case of specific cultural heritage materials like metals and alloys, with the analogous X-ray imaging [Lehmann et al. (2011); N. Kardjilov et al. (2011); G. Bevan et al. (2013)].

While traditional analytical techniques might fail to preserve the integrity of the objects, neutron imaging methods can be successfully used to characterize the structure, morphology and composition of metal artworks three-dimensionally without the need for sampling or invasive procedures. These physical properties of an artefact are the imprint of its manufacturing process and of its life cycle. They can be convincingly reconstructed through a careful analysis of the material evidence.

In collaboration with museum institutions and university research groups, archaeometric investigations have been recently conducted by using the neutron imaging beamline DINGO at ANSTO [Garbe et al. (2015)]. A selection of case studies is presented in this paper focusing on the understanding of the processes used in the manufacture of a set of ancient metal artefacts through the characterization of their inner structure and morphology.

2. Methodological approach

The neutron tomography analyses were performed on DINGO, the ANSTO neutron imaging instrument located on a thermal beam tangentially facing the 20MW OPAL research reactor in Sydney [Garbe et al. (2015)].

Industrial processing, geoscience, palaeontology and civil engineering [Salvemini et al. (2016)] are the major applications in the utilization of the instrument. Additionally, research in the field of cultural heritage has also benefited from the use of neutron tomography. The flexibility of the DINGO layout allows the non-invasive analysis of samples of different sizes at the required spatial resolution, whose limit is imposed by the method and the current instrumental equipment.

The neutron tomography studies discussed in this paper were conducted in high resolution acquisition mode (length to diameter L/D ratios of 1000). In order to investigate large objects (case studies sections 3.1 and 3.2), a field of view of 200x200 mm^2 was used. This configuration features a pixel size of 100 µm and a 50 mm lens with a ^{6}LiF/ZnS scintillation screen 100 µm thick was adopted. Projections were acquired every 0.25° over 360° with an exposure time of 15 s per projection. Since the length of samples exceed the actual size of the field of view available, consecutive tomographic scans, from 2 to 4, were acquired to investigate the entire artefacts. A superimposition of a few centimeters between scans allowed precise stitching of the individual tomographic reconstructions into a full 3D model of each sample during data processing. In some cases, it was not possible to investigate the whole volume due to the length of the sample and limited run of the samples stage along the vertical direction. An overall measuring time of about 12 hours was required per each scan.

A pixel size of 27 µm (case study 3.3) was obtained by setting a 55x55 mm^2 field of view with 100 mm lens, coupled with a ^{6}LiF/ZnS scintillation screen 50 µm thick. In this configuration, projections were acquired with an equiangular step of 0.25°over 360° and an exposure time of 50 s each, resulting in a total scan time of about 20 hours.

The tomographic reconstructions were obtained by using Octopus package [Dierick et al. (2004)] while AVIZO [https://www.fei.com/software/avizo3d/] was used for data visualization, stitching and quantification.

3. Case studies

3.1. A forensic study on ancient Japanese swords

Exceptional hardness, resilience and appearance make Japanese swords one of the most valued weapons of ancient and modern times [Yumoto (1958)]. These distinctive features derive from the quite unique manufacturing technique developed by sword-smiths. Historically shaped by the conjuncture of Japanese politics, economy and culture, the actual evolution of their manufacturing techniques is still not fully understood, especially aspects of