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Method article

Neutron microtomography of voids in gold

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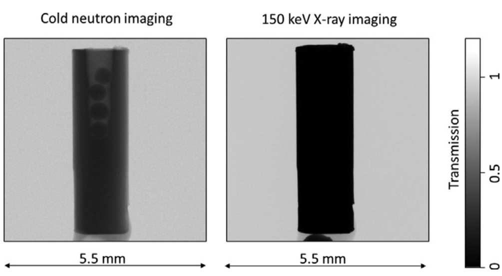
HIGHLIGHTS

- High-resolution microtomography of gold sample with artificially induced pore space.
- Comparison of the individual neutron radiograph with radiograph based on a common commercially-available tabletop X-ray source.
- Demonstration of potential for high resolution non-destructive quantification of porosity in other high atomic number materials (such as, precious metal alloys).

GRAPHICAL ABSTRACT



ABSTRACT

Pilot attempt of the neutron microtomography of voids in gold carried out using the Neutron Microscope instrument is presented in the paper. The paper demonstrates that neutron microtomography provides viable alternative to X-ray imaging for the assessment of porosity in high atomic number materials. The model sample based on gold with artificially induced void system reveals segmented porosity with 5.4 micrometres voxel size and the spatial resolution close to 10 micrometres.

ARTICLE INFO

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Method details

Imaging with neutrons has been utilized for number of niche applications in which imaging with other types of radiation (such as X-rays) provides less convenient probe. One such example of niche application is imaging of microstructure of some very high atomic number materials [1–3], in which radiation in (hard) X-ray regime does not provide sufficient transmission signal to reveal the inner structure of such materials. The different contrast mechanisms of neutrons with matter (to that of X-rays) allow for investigation of materials based on high atomic number elements.

Objects made of high atomic number elements have been investigated using neutron imaging (i.e. tomography) already for some time [4]. It is, however, the recent progress in neutron imaging instrumentation (sub-10-μm domain) [5] that allows for imaging of representative volume elements of high atomic number materials with desired high spatial resolution.

In this paper, it is demonstrated that high-resolution neutron microtomography can readily reveal voids in high atomic number materials with high spatial resolution in (for neutron imaging) affordable acquisition time. For the purpose of this demonstration, a sample of gold with artificially induced porosity has been prepared and investigated at the Paul Scherrer Institut, at ICON [6] and BOA beamlines [7] using the Neutron Microscope instrument [5,8].

Sample preparation and test arrangement

In order to demonstrate the feasibility of high-resolution neutron microtomography of porosity in high atomic number materials, a sample of gold with artificial void system has been produced in the following manner. First, a small gold rod of 1.6 mm in diameter and of approximately 5 mm in length was cut from a longer piece of commercially available high-purity gold rod. A small hole – of about 2.5 mm in depth– was drilled into one side of the rod using a 0.5 mm drill. The resulting hole was filled with four commercially available gold spheres of 0.5 mm in diameter. The sample has been then imaged at the ICON beamline [6] using first high-energy X-rays and later neutrons. Both X-rays and neutron radiation has been detected using approximately 3.5 μm thick isotopically-enriched 157-gadolinium oxysulfide scintillator screen [9]. The resulting visible light was magnified by high-numerical aperture optics and collected using a high-performance CCD detector. The nominal pixel size of the radiographic images taken at ICON beamline was equal to 2.7 μm and the full field of view of 2048 $\times$ 2048 pixels was thus equal to approximately 5.5 $\times$ 5.5 mm $\times$ mm. A commercially-available table-top X-ray source provided high-energy X-rays and was set to 150 keV accelerating voltage and 500 mA beam current. The distance between the X-ray source and the scintillator screen was approximately 400 mm. The neutron radiographs were taken using the full white beam available at the ICON beamline. The size of the beam defining aperture was equal to 20 mm in diameter and the distance between the detector and the aperture was about 8.7 m, leading to L/D ratio of about 435. Stacks of individual projections of 60 s acquisition time were taken both for X-ray and neutrons.

After that the Neutron Microscope instrument and the small gold sample was transferred to BOA beamline [7], where beamtime availability allowed for a microtomography experiment to be performed. During the transfer, the top most gold sphere fell out of the sample and therefore the sample with three gold spheres only was tomographed using the following test arrangement. The size of the beam defining aperture was equal to 40 $\times$ 40 mm $\times$ mm and the distance between the detector and the aperture was about 5.5 m, leading to L/D ratio of about 138. The mean distance of the sample and the scintillators screen was equal to about 1 mm.

Projections images were acquired in 225 angular positions spread uniformly over 360 $^\circ$ travel range (step size 1.6°). In each angular position 11 individual radiographs of 60 s exposure time were taken. For the purpose of affordable acquisition time, 2 $\times$ 2 pixel binning was used directly at the detector, leading to a pixel size of 5.4 μm and the full field of view of 1024 $\times$ 1024 pixels.

In order to suppress the white spots in the images, the resulting radiograph in each angular position was obtained as a median filtered image of all the 11 projections. Thus, 2486 individual projections were taken over the course of about 5 days of experimental time. However, it needs to be highlighted that the experiment has been halted in the process of the acquisition by unavailability of