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Comparison between neutron tomography and X-ray tomography: A study on polymer foams

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ABSTRACT

This work aims at discussing the possibilities of high resolution neutron tomography, in comparison to conventional cone beam X-ray CT, based on the results on a set of polymeric foamed materials. The neutron experiments have been carried out at the V7/CONRAD-2 imaging instrument located at the BER-2 research reactor at HZB and compared to the images obtained in a X-ray CT system based on a microfocus tube and a flat panel detector. This type of materials has not been previously examined with neutron imaging. The enhanced neutron attenuation relative to the X-ray attenuation and the recent development of high-resolution neutron imaging detectors encouraged this investigation. The results point to a better signal-to-noise ratio of the X-rays in comparison with current neutron tomography – due to the rather low neutron flux. Nevertheless the contrast of polymeric materials in neutron imaging offers further possibilities for future developments in high resolution neutron tomography.

1. Introduction

Cellular polymers consist in gaseous phase dispersed into a solid continuous polymeric matrix. The air inclusions confer this material new and advanced properties that extent the properties of conventional solid plastics [1–3]. Typical densities of these materials range from 25 up to 500 Kg/m^3. These lightweight materials are important because of technical, commercial and environmental issues since they success in mechanical, thermal and acoustic behaviour whereas they save raw material and thus production costs. [4] and, due to this demand, they are under continuous development by both scientific and industrial communities.

Conventionally, structural characterization of these materials is carried out by using 2D cross-section images (optical/electrical microscopy) [5,6]. In recent years, non-destructive 3D methods, namely X-ray microtomography (mCT but in the following denoted as X-CT), have been progressively applied for the characterization of these materials although it is not easy to resolve their structure due to the "unlucky" combination of lightness (some materials are up to 98 vol.%. air, with densities such low as 25 Kg/m^3), the low X-ray absorption of the polymeric matrix and the thin-structured cell walls (sometimes bellow 1 micron, i.e. near to the limits of X-CT resolution). All these reasons hinder the study of the cellular structure of these materials by conventional X-CT equipment (including nanofocus systems). Only in the case of synchrotron-based tomography it possible to reach real higher resolutions as currently demonstrated by recent nanotomography advances [7,8]. The resolution deficiency causes later problems during the reconstruction of the real cellular structure. As a result, typically, a high number of cell walls are missing and watershed-based separation algorithms become necessary to approximately reconstruct them [9] although, sometimes, it is necessary to exactly resolve all the cell walls.

The advantage of neutron tomography (N-CT) in comparison with X-CT is based on the enhanced neutron attenuation of polymers (which contain high % hydrogen in their molecules) and therefore the contrast for such structures is expected to be higher. The limiting factor is the spatial resolution provided by the neutron detectors which is not as high as in X-ray systems. Nevertheless, the latest developments at V7/CONRAD-2 instrument made possible to reach a resolution of 15 µm in radiographic images [10]. This was possible by optimization of the optical system of the detector setup by application of infinity corrected optics which allows for optical magnification. In this way the limitation of the pixels size of the detector was overcome. New type of scintillating screens based on Gd_2O_2S (Gadox) were a key factor to improve the quality of the image by reducing the thickness of the screens down to 10 µm. The beam collimation is essential in case of high-resolution imaging therefore high collimation ratios (L/D values) were used at

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the neutron imaging instrument CONRAD-2. The unique characteristics of the instrument: high-intense cold neutron beam with low background (small fraction of gammas and high-energetic neutrons) helped to achieve acceptable signal-to-noise ratio for high-resolution experiments at reasonable exposure times in the range of 40–60 s per image. This opened the possibility of performing tomography experiments where several hundreds of sample projections are recorded.

The interest of exploring this technique and examining the maximum real resolution of neutron tomography motivated this work and the use polymer foams as challenging, thin-structured resolution testing probes. As a summary, this research aims to perform a comparison between N-CT and the extensively used X-CT in polymeric foams for a first time.

2. Experimental

2.1. Computed tomography methods

2.1.1. X-ray microtomography (X-CT)

The X-CT system used at Helmholtz-Zentrum Berlin consists in a micro-focus 150 kV Hamamatsu X-ray source with a tungsten target and a flat panel detector C7942 ($112 \times 118\ mm^2$, $2240 \times 2368\ pixel^2$, pixel size 50 mm). Fig. 1 shows a photography of the system used. A 50 kV filament voltage and a current of 200 µA with an exposure time of 2 s were used in these scans since these parameters provided the best results. Image noise was reduced by using a 4-fold integration thus providing 16 bits image output. The source-object distance was 60 mm and a source-detector distance of 400 mm was used, thus achieving a magnification factor of 6.67. The number of acquired projections varied in between 800 and 1200 images which yields a total scanning time was in between 2 and 4 h. In the X-ray cabinet, the sample was rotated in a precision rotation stage from Huber, Germany. A commercial software (Octopus V8.6) was used to implement the back-projection algorithm with convolution and correction for cone beam, so the internal structure of the foam was reconstructed. The voxel size of the reconstructed volumes was approx. 7.5 microns.

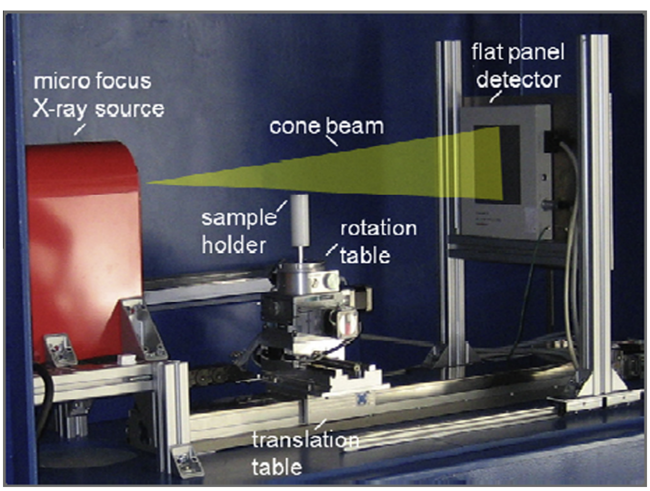

Fig. 1. Photography of the microfocus CT setup at HZB. The details of the setup are described in the text. The distance between the source and the detector is 600 mm.

2.1.2. Neutron tomography (N-CT)

The neutron tomography instrument CONRAD at Helmholtz-Zentrum Berlin is located at a curved neutron guide at the BER-II research reactor [11]. The curved guide closes the direct view to the reactor core and acts as a filter which eliminates the high energetic neutrons and gammas from the core. In this way the neutron spectrum at the end of the guide has a maximum at 2.5 Å –the so-known "cold" neutrons– which show higher sensitivity to hydrogen and other light elements like lithium and boron. The facility uses a pinhole geometry with variable diameters, D, at the end of the guide (D = 1, 2 or 3 cm) and a fixed flight path between the pinhole and the detector of L = 10 m. For the experiments presented in this study pinhole diameters of 3 and 2 cm were used reflecting in collimating ratios L/D of 330 and 500, respectively. Fig. 2, shows the schematics of the configuration at CONRAD beamline. The detection system is high-resolution setup consisting in an assembly of Gadox scintillator, lenses and a 16-bit cooled 2048×2048 pixels CCD camera. Yielding a pixel size of 6.43 µm and Field-of-View (FOV) of 13×13 mm [12]. Exposure time was between 20 and 30 s and two images per step (integration) were taken. An erosion filter (taking the MIN value from the two images) was applied in order to suppress the large number of white spots in the images. The tomography experiments were performed with 600 projections reflecting in a total measuring time from 7 to 10 h per tomogram.

Table 1 summarizes the main characteristics of the two imaging systems used.

2.2. Materials

Different foams produced at CellMat Laboratory by two different methods (improved compression moulding and extrusion

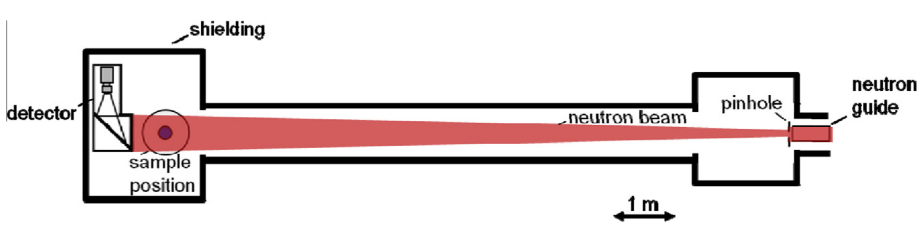

Fig. 2. Layout of the neutron imaging instrument CONRAD-2 (top view). The distance from the aperture to the sample position is 10 m.

Table 1
Main parameters of the imaging systems.

Technique	Energy	Voxel size (µm)	Detector size (mm)	Magnification	FOV (mm)
X-ray CT	50 kV	7.5	120 × 120	1:6.67	18 × 18
Neutron CT	10 meV	6.5	13 × 13	1:1	13 × 13