X-ray tomography characterization of the impact of compression on the microstructural properties of a packing of hemp shiv particles

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Abstract

The use of sustainable materials like bio-based building materials is a significant step toward carbon neutrality by reducing CO emissions. Given that their performances are closely tied to their microstructure, it is essential to understand and link microstructural properties to the multiphysical behaviors of these materials.

This study aims to analyze the microstructural evolution of a hemp shiv packing under varying compression states. X-ray tomography images were acquired at the Soleil Synchrotron facility (Anatomix beamline), providing valuable information into the three-dimensional structure of the particles and their internal pore network that cannot be obtained using other techniques.

Scans were performed on cylindrical samples measuring 40mm in diameter and 40mm in height. The scans were performed in a loose state and under four compression states (sample density ranging from 130 to 844 kg/m3).

In addition to classical absorption reconstruction of the tomography data, a phase-enhancement Paganin (1) filter was used to improve the contrast of the images of this low attenuating material. However, the image analysis still faced several challenges: (i) high intra- and inter-particle porosity reduced image contrast, particularly at particle boundaries, which are critical for the individual segmentation of the shiv particles; (ii) the complex morphology of hemp shiv particles displays diverse shapes and sizes, (iii) the application of the Paganin filter accentuated artifacts in the images; and (iv) the large dataset size required using high-performance computational resources for efficient analysis.

Thus, convolutional neural networks were used to segment the hemp shiv packing. Semantic segmentation was achieved using deep learning, with training data generated by manually labelling the particles and assigning distinct labels to the surrounding sample (air). The "generic U-Net dl-7 ifc32" model, of the Dragonfly ORS software (2), was employed for this task. After training, in all 3 directions of space, the model was successfully inferred on the

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whole volume.

The individual segmentation of hemp shiv particles was based on their structural and spatial properties. Initial separation was performed by applying a threshold to eigenvalues derived from the structure tensor of the particle packing. These eigenvalues generated markers for a watershed algorithm. Further local separation was needed for wrongly merged particles, using a distance map and applying a local watershed algorithm. The initial labels were refined iteratively to ensure accurate particle separation.

The porous volume of the sample was analyzed using Dragonfly ORS, with the OpenPNM (3) plugin implementing PoreSpy's SNOW algorithm. This allowed modelling pores as spheres and throats as cylinders which resulted in the assessment of pore size, volume, position, and connectivity.

Finally, the local density of hemp shiv particles was examined with the help of calibration scans performed on materials with known densities. Assuming a linear relationship between X-ray attenuation and material density (Beer-Lambert's law), the density of hemp shiv particles was determined by correlating grey values with known densities from calibration data (4).

Despite the data's complexity, both qualitative and quantitative information were obtained, filling gaps in the literature and accentuating the value of X-ray tomography for studying such materials. The image analysis techniques developed for these granular media are not only applicable to bio-based materials but can also be extended to study other granular materials, especially those with complex geometries and challenging contrast conditions.

References:

(1) Paganin, D., Mayo, S. C., Gureyev, T. E., Miller, P. R. and Wilkins, S. W. (2002), Simultaneous phase and amplitude extraction from a single defocused image of a homogeneous object. Journal of Microscopy, 206: 33-40. doi: 10.1046/j.1365-2818.2002.01010.x

(2) Dragonfly 2022.2 (Computer software). Comet Technologies Canada Inc., Montreal, Canada; software available at https://www.theobjects.com/dragonfly.

(3) J. Gostick, M. Aghighi, J. Hinebaugh, T. Tranter, M. A. Hoeh, H. Day, B. Spellacy, M. H. Sharqawy, A. Bazylak, A. Burns, W. Lehnert, and A. Putz: OpenPNM: A Pore Network Modeling Package, Computing in Science and Engineering, 2016, vol. 18, p. 60–74.

(4) P. Glé, T. Lecompte, A. Hellouin de Ménibus, H. Lenormand, S. Arufe, C. Chateau, V. Fierro, A. Celzard: Densities of hemp shiv for building: From multiscale characterisation to application, Industrial Crops and Products, 2021, vol. 164, p. 113390.