Resolution Dependency of Sandstone's Physical Properties

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Aims

Study on the physical properties of rocks in macro-scale (e.g., permeability, seismic velocity, electrical conductivity) has indicated that the macro-scale properties are greatly depend on the microstructure parameters, such as pore size, grain size and its distribution, pore connectivity, etc [1]. With the rapid development of computing technology, non-destructive analysis using computational approach has become promising alternative to experimental approach. In order to produce reliable results, one must be able to provide decent digital representation of the rocks, which can be obtained from X-ray computerized micro-tomography (µ-CT) [2]. The resolution of the produced digital data can be selected with regards to the details to be analyzed. This paper presents analysis on the dependency of the computed physical properties of a Sandstone sample to the resolution of the produced digital representation obtained from the µ-CT scanner.

Method

A Skyscan 1173 µ-CT scanner at the Basic Science Advanced Laboratory of Bandung Institute of Technology was utilized to produce these digital data. The µ-CT images were reconstructed by the NRecon software. CTAn was utilized to calculate the porosity and the percentage of isolated pores. The tortuosity and permeability were calculated using a free Parallel Lattice Boltzmann Solver (Palabos) [3] combined with Paraview [4]. Several other analyses and image manipulation were done using ImageJ [5].

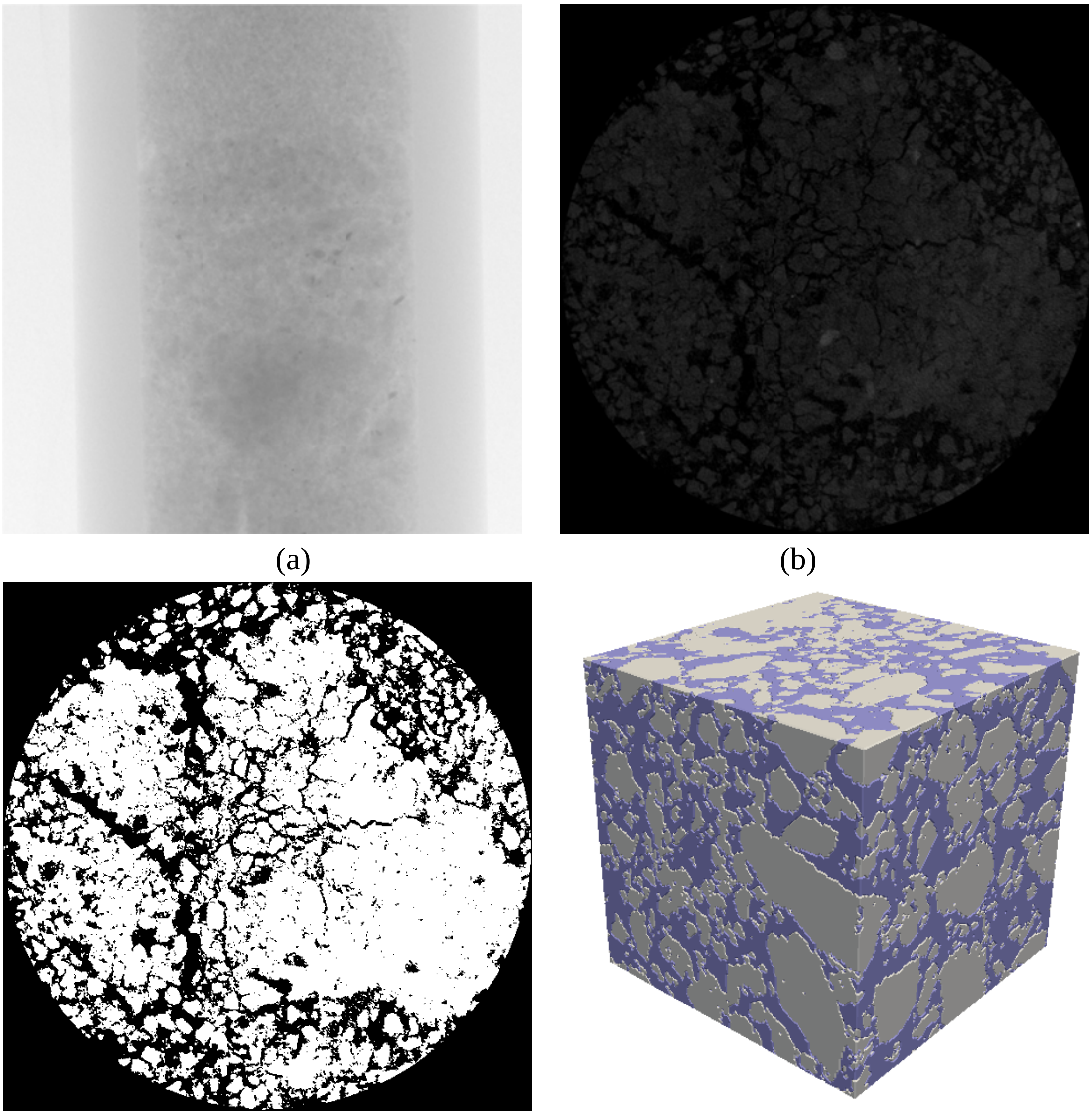
The scanned sample is a loose-Sandstone obtained from Blora, Central Java, Indonesia, with the diameter of 6mm and length of 13 mm (see Figure 1).

Figure 1: Loose Sandstone sample from Blora, Central Java, Indonesia.

The sample was scanned at three different resolutions, i.e., 7.5 µm, 15 µm and 30 µm, obtained from camera binning of 1x1, 2x2 and 4x4 respectively. For further processing, we generate a cubical subsample with the dimension of 2.25 x 2.25 x 2.25 mm.

Results

The produced projection image is shown in Figure 2a (at 0.20°). The 2-D slice of the reconstructed image can be seen in Figure 2b; the reconstructed 2D slices are then converted to binary images, by defining a region of interest (ROI) and a thresholding value. In this case, the white is the solid phase (matrix) of the rock, while the black ones are the pore space. Figure 2d is the three dimensional visualization of the cubical subsample with the grey being the solid phase.



(a) (b) (c) (d)

Figure 2: (a) Projection image of the sample (b) reconstructed image at pixel resolution of 7.5 µm (c) the corresponding binary image obtained from thresholding image (b) three dimensional visualization of the cubical subsample.

Analyses were conducted on the three sets of cubical subsample from the reconstructed images. Three 2D slices from the cubical subsample can be seen in Figure 3.

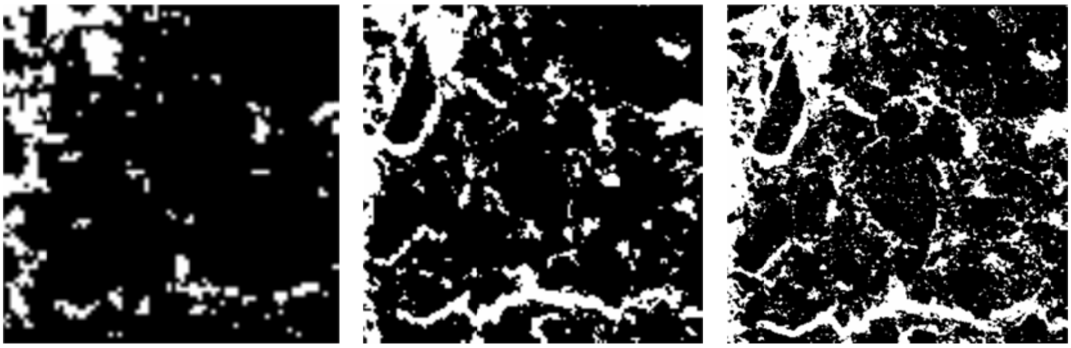


Figure 3: Two dimensional slices of the cubical subsample with pixel resolution of 30 µm (left), 15 µm (center), and 7.5 µm (right).

To analyze the dependency of physical properties of the rock to the scanning resolution, we first calculate the porosity, the percentage of the closed pores, and the specific surface area. As we can see in Figure 4, significant number of pores are failed to be detected from the image obtained at the lowest resolution. Isolated pores are also more likely to exist in the low resolution reconstructed images. This proves that at the lowest one (30µm) significant detail of the interconnected small pores are missing. However, the difference in the specific surface area is not too significant.

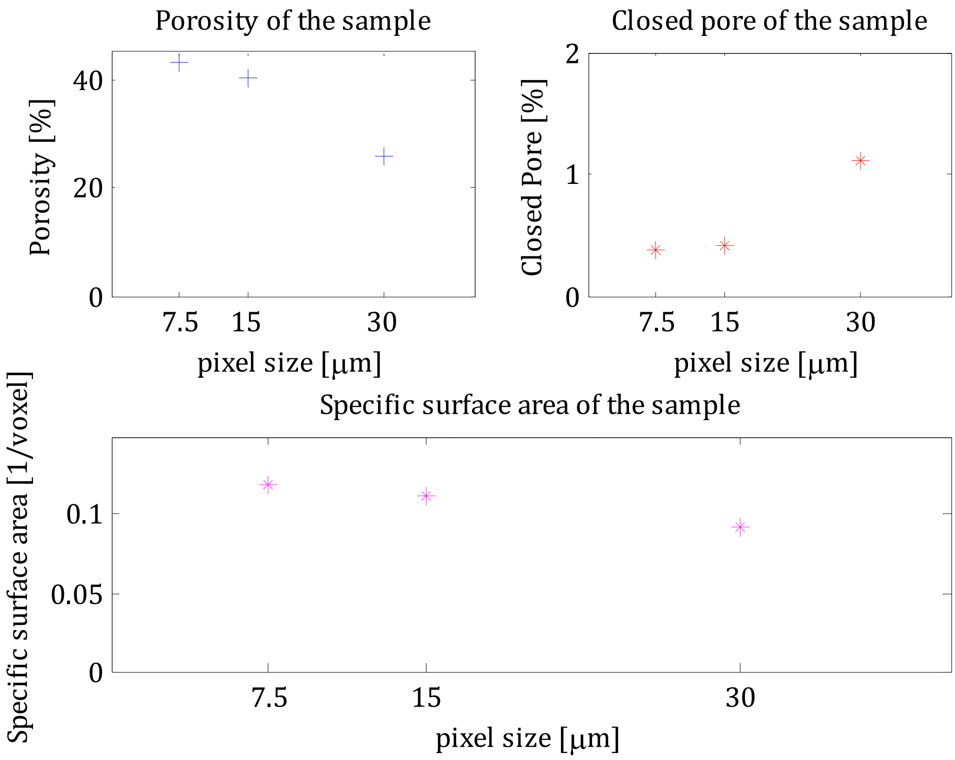


Figure 4: Plot of porosity, percentage of closed pores and the specific surface area of the three reconstructed samples.

The next two significant physical properties of the rock are the tortuosity (the complexity of the flow path inside the pore space) and the permeability. Figure 5 shows the plot of tortuosity and permeability versus the pixel size. We can see that the data with lower resolution has higher value of tortuosity, which indicates that the structure of the interconnected pores is more complex. This is confirmed by the plot of permeability.

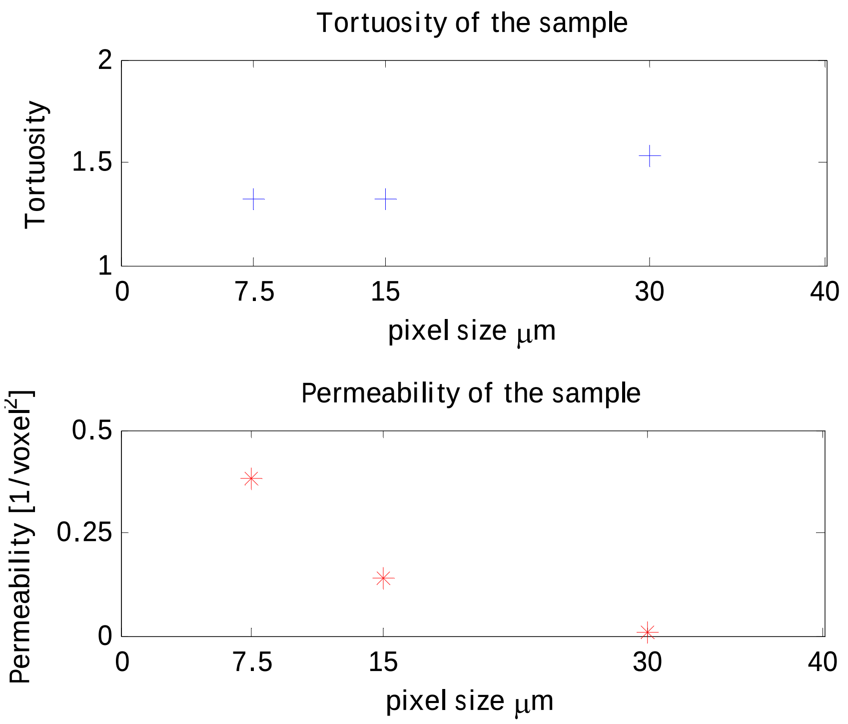


Figure 5: Plot of tortuosity and permeability with regards to the pixel size.

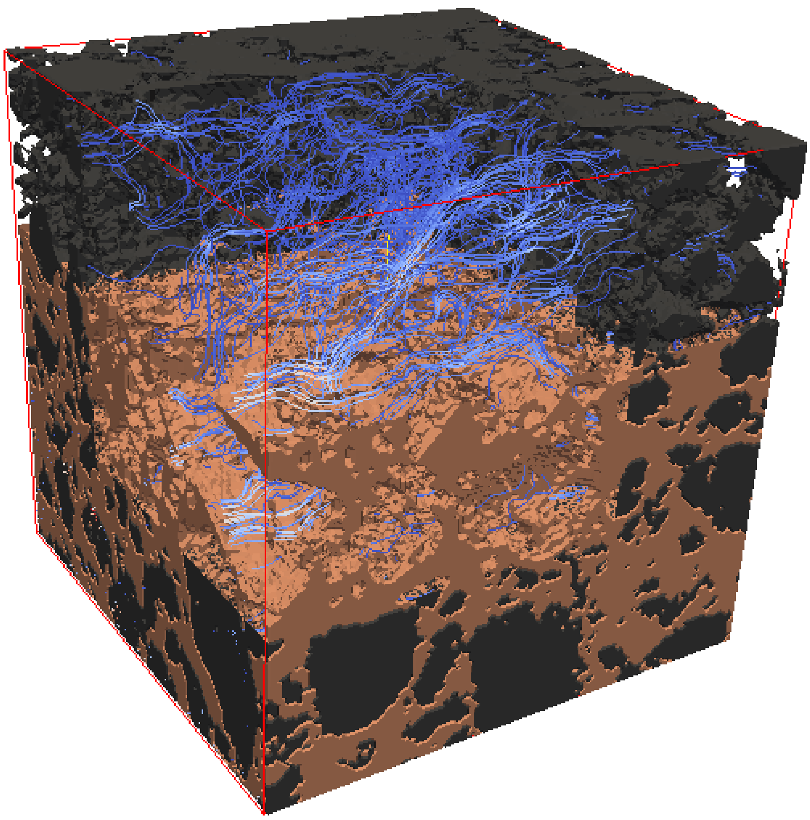


Figure 6: Three dimensional representation of the pore space (brown), the solid phase (black) and the streamline produced from computer simulation of fluid transport.

In addition to the analyses above, one of the advantages in having 3D reconstructed images is that we can conduct many other analyses through various computational methods. One of the most interesting studies is the computer simulation of fluid transport in porous medium. Figure 6 shows the three dimensional representation of the pore space (brown), the solid phase (black) and the streamline produced from the computer simulation of fluid transport.

Conclusion

The procedure of obtaining a representative 3D digital data of rock can be easily done using computed microtomography. This technique provides an input for further detailed non-destructive characterization of the pore structure at micro-scale. Porosity, percentage of closed pore, specific surface area, tortuosity and permeability can be easily calculated using various tools.

This however, have some pro and cons. Detailed reconstructed samples are obtained from high resolution scanning which later produce large datasets. The processing of such large dataset will consume huge computing resource. On the other hand, using small datasets obtained from scanning samples at low resolution will promote the risk of missing significant details.

From the study in this paper, we can conclude that for rock sample, several physical properties have high dependency to the resolution of the reconstructed images. Aside from the resolution dependence however, these characterizations were able to provide valuable data in order to understand the properties of rock in particular. Furthermore, using the reconstructed 3D image, we were able to simulate the fluid transport which in most cases of rock study can be considered as one of the most important aspect.

References:

1. Latief FDE, Fauzi U, “Kozeny–Carman and empirical formula for the permeability of computer rock models”, Int J Rock Mech Mining Sci, 2012, doi:10.1016/j.ijrmms.2011.12.005
2. Dunsmuir J, Ferguson S, D’Amico K, “Design and operation of an imaging X-ray detector for microtomography”, Phys Lett, 121:257–61, 1991
3. www.palabos.org
4. www.paraview.org
5. http://rsbweb.nih.gov/ij/