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# Evaluation of Tortuosity in Cemented Sand Using X-Ray Computed Microtomography

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## 1 Introduction

Pore network in cemented sand is an important design parameter but difficult to quantitatively analyse. Hence, several experimental parameters are frequently being used to understand pore network and resulting durability of the system. Tortuosity is a meaningful parameter that has a significant impact on flow and transport characteristics of porous media. Therefore, the knowledge of tortuosity for cemented sand is strongly required for designing not only the cement content for soil stabilization but also evaluating the life span of cementitious materials under various environments. This study aims to investigate the tortuosity of the cemented sand with different cement content from the X-ray computed tomography (CT) based random walk simulation.

## 2 Materials and Methods

The specimens of cemented sand used in this study were prepared by mixing sand and ordinary Portland cement Type 1. Water content which means the ratio of mass of water to solids (includes both sand and cement) is 0.1 The X-ray imaging of specimens was performed by the Skyscan micro-CT. Acquired reconstructed image from tomographic data has 1000×1000 pixels with a pixel resolution of 5 μm/pixel. Segmentation was carried out to separate pore from solid part. After pore segmentation, 1000 slices of 2D images were merged to reconstruct the 3D pore space to implement further processing of random walk simulation. Watershed algorithm was applied to binary segmented image for severing connected sand fragments.

Then, a 3D random walker simulation (Nakashima and Kamiya, 2007) implanted in MATLAB was used to compute the tortuosity. To execute the random walker simulation, a random pore voxel in the inter-connected pore network was chosen as the initial position of each walker. In each timesteps, the one was selected among the six voxels which are face-to-face connected with the random walker. Then the random walker migrated to the selected voxel if the voxel was pore space. The average displacement of the walkers was plotted as a function of the number of the timesteps and the tortuosity was calculated from the inverse of the slope of this curve.

## 3 Results and Discussion

An example of the results from image analysis of the VOI is shown in Figure 1. Segmented solid phase is corresponding to the sand and cement particles including both hydrated and unhydrated. All pores found in cemented sample were connected. The segmented porosity decreases as the cement content increases with one exception of 0% cement sample (not shown here). Figure 2 shows the diffusion tortuosity of each sample calculated by random walker simulation on the segmented pore space (*i.e.*, interconnected pore). The diffusion tortuosity increased with cement content increased. This implies that the pore space is being more tortuous as more cement added in the system. Cement hydrates adhere to the surface of sand particles partially and make surface rough.

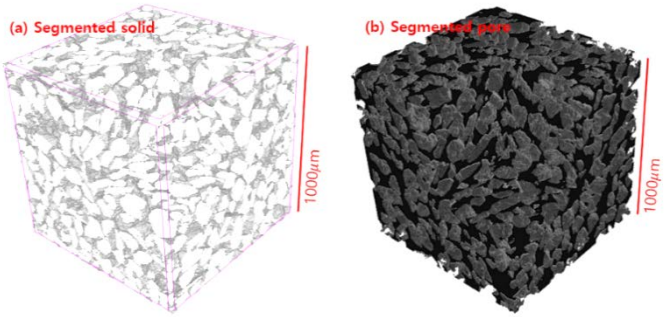


**Figure 1.** Visualization of pore space from microtomographic images of the 1% cemented sand sample ($\mathbf{1000^3}$ voxels). (a) binary image of segmented solid phase. (b) binary image of segmented pore phase.

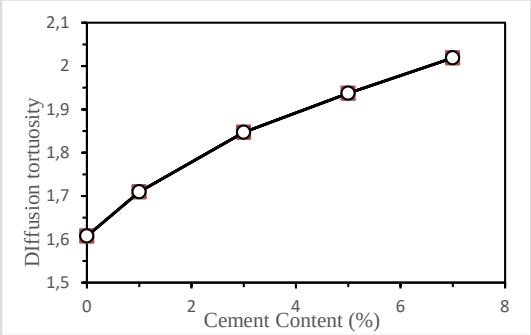


**Figure 2.** Relationship between the diffusion tortuosity and cement content for cemented sand sample.

## 4 Conclusion

The porosity and tortuosity parameters obtained from the tomography data here provide an indication of the pore network geometry and microstructure of cemented sand. Higher cement content gave an increase in tortuosity and a decrease in porosity. This indicates that the addition of cement hydrate in compacted sand, makes pore space more tortuous. The quantitatively obtained pore structure data will be helpful for theoretically calculating the permeability and diffusion coefficient which are being considered as important parameters for evaluating durability performance of solid materials.

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