Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Computed Tomography Image based Analysis of Concrete Microstructure

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Keywords : virtual element method, polygonal elements, concrete microstructure, image-based analysis

1. Introduction

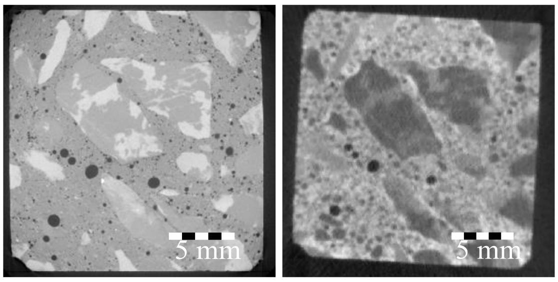
Recent advances in the use of composite materials cause, microstructural analysis is essential to understand the macroscopic behavior of complex composite materials. Additionally, advances in imaging technology make it possible to directly utilize actual micro-structures for finite element analysis. However, previous studies generally applied pixel data directly to analysis due to the structural complexity of the microstructure [1-2]. In this pixel-based finite element method (FEM), each pixel corresponds to a quadrilateral element in a finite element mesh. Although these methods are simple to discretization, but it lead to high computationally cost.

The purpose of this study is to efficiently and effectively analyze the microstructure. The micro-structure of concrete was successfully reconstructed using the complementarity of X-ray and neutron computed tomography(CT). Proposed an image-based virtual element method(VEM) for reconstructed micro-structure analysis. VEM can consistently handle polygonal elements of arbitrary shape. Generate a polygonal mesh for analysis based on image. Numerical results effectively capture the macroscopic behavior and stress concentration.

2. Microstructure Reconstruction

In this study, microstructural analysis was performed on concrete, a representative composite material. Structural information on the microstructure of concrete was obtained using a reconstruction method using the complementarity of X-ray and neutron CT from a previous study [3].

CT image was capture by the concrete specimen for the size of 20mm x 20mm x 80mm. X-ray tomography was taken from the Korea Institute of Civil Engineering and Building Technology; neutron tomography was acquired from RAD facility of the Centre for Energy Research in Hungary. The X-ray and neutron CT images are selected for a certain plane of the specimen, as shown in Figures 1(a) and (b), respectively. The pixel sizes of X-ray and neutron CT images are 13.8 μm and 43.0 μm, respectively.



(a) (b)

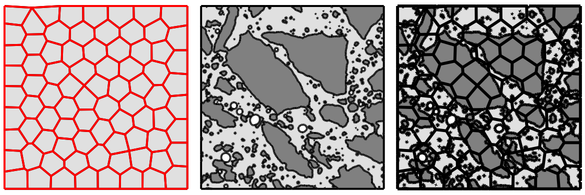
Fig. 1. Digital image for the concrete specimen. : (a) X-ray CT, and (b) Neutron CT.

First, the size of the neutron CT image is adjusted to match the higher resolution X-ray CT image. Next, registration of the two images using a minimization technique based on the void pattern. The centers of the three largest voids are used as reference points, and the rigid body translation and rotation values are calculated. The reconstructed microstructure is identified into three phases: pores, aggregate, and paste. Based on the high image resolution, a set of void pixels of the reconstructed area is obtained from the void pixels of the X-ray CT image. The aggregate pixel set is defined as the difference of the void pixel set to the sum of the aggregate pixels of the two CT images. This stems from the problem that some voids are identified as aggregates in a single CT image. The set of paste pixels is confined to the remaining area. Open-closed morphological filtering [4] is used to remove the noise errors caused by the image acquisition and processing. The radius of the filter domain is 4 pixels. And filtering on the partial domain(aggregate and paste) to avoid affecting voids. It should be noted that the reconstructed microstructure has a wide range of length scales due to small pores and large aggregate particles and is used directly for image-based analysis.

3. Image based Virtual Element Method

To efficiently analyze complex microstructure, the image-based virtual element method(VEM) is utilized[5]. Polygonal elements have been widely utilized because of the flexibility on the element shape. While the integration using the non-polynomial shape functions on arbitrarily polygonal elements is computationally challenging. To consistently handle the non-simply elements, the VEM was proposed by implicitly defining shape functions of polygonal elements in conjunction with the projection operators.

For the image-based analysis, the concrete micro-structure is discretized by the polygonal elements. Polygonal mesh is generated through integrating homogeneous and microstructure meshes for a given domain. A homogeneous mesh is constructed using the centroidal Voronoi tessellation(CVT), while micro-structure mesh is generated on the basis of the concrete microstructure. These two meshes are integrated through creating nodes, edges, and elements, which leads to a mesh for the image-based VEM[5].



(a) (b) (c)

Fig. 2. Schematics of the polygonal mesh generation with a: (a) homogeneous mesh, (b) microstructure mesh, and (c) integration of homogeneous and microstructure mesh.

4. Computational Result

Image-based VEM[5] is used for microstructural analysis to analyze the mechanical behavior of composite material. To verify the effect of the microstructure on the structural behavior, the uniaxial tension test is analyzed. A square domain of 18.023 × 18.023 mm (1,306 pixel × 1,306 pixel) is employed, as shown in Figure 3. The bottom edges of the domain are fixed along the vertical direction, and the top edge is applied uniform displacement of 18.023 μm along the vertical direction. It is leads to the average macroscopic strain of 0.001 under the plane stress condition. The composite material has three cases. The elastic moduli of matrix(light gray) is fixed as 30GPa. The cased of particle(gray) is assumed as 10GPa, 30GPa, and 50GPa. The Poisson's ratio of the particle and matrix are 0.25 and 0.2, respectively. For the image-based VEM, the number of elements of meshes are 11,626.

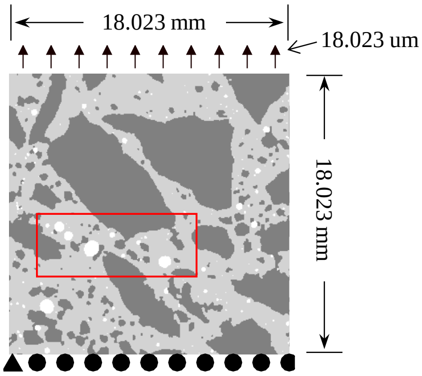
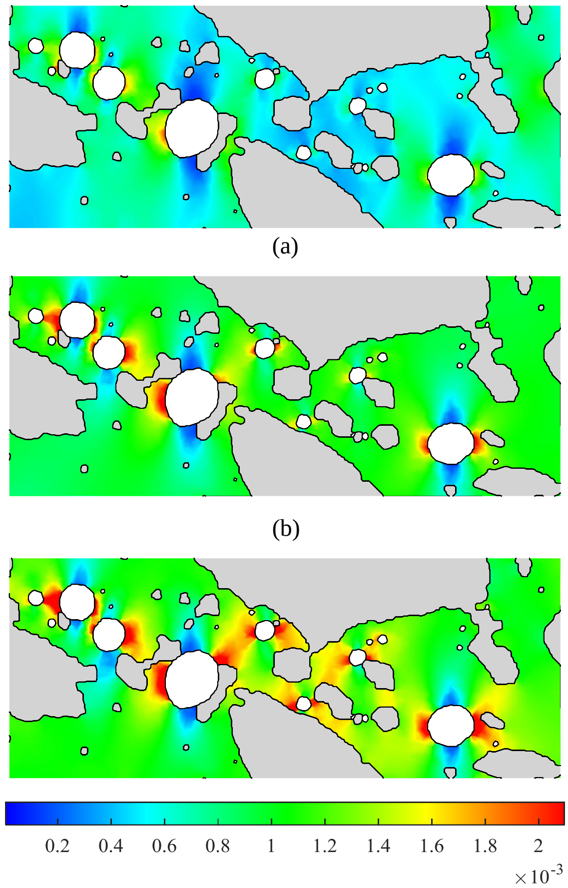


Fig. 3. Geometry and boundary conditions of the uniaxial tension test on the microstructure of composite material

Analysis result demonstrates that the macroscopic elastic modulus for the each cases calculated by 17.195 GPa, 29.911 GPa, and 37.372 Gpa, respectively. The macroscopic elastic modulus is simply computed using the average macroscopic strain and the average reaction force on the domain boundary. As the elastic modulus of the particles increases, the macroscopic elastic modulus increases, and even the elastic modulus of the particle and the matrix are same, macroscopic elastic modulus is a lower than due to the voids.

Figure 4 demonstrate the effects of the microstructure and relation between elastic modulus of each material phases. It is the maximum strain field on the matrix according to the elastic modulus of the particle. To identify critical points due to concentration of the strain in the matrix around the voids the red rectangular region in Figure 3 was zoomed. Applied uniaxial tension on the vertical direction, a high value of tensile strain occurs in the horizontal direction around the void. And, as the elastic modulus of the particle is relatively higher than matrix, the tensile strain on the matrix near the void and the matrix between adjacent particles is increases relatively.



(c)

Fig. 4. Distribution of principal strain on the matrix depend on the elastic modulus of the particle: (a) smaller than, (b) the same, and (c) larger than the matrix

5. Conclusions

The complementarity of X-ray and Neutron CT, the concrete microstructure is effectively reconstructed. A morphological filtering technique is employed to reduce tiny aggregates of a few pixels and remove artificial aggregate layers. For the analysis of complex microstructure, using the image-based VEM through integrating the homogeneous and microstructural meshes. Microstructure mesh based on the image, more efficient discretization of complex microstructures is performed. The microstructure analysis of complex geometry was performed well using image-based analysis. Numerical result demonstrate that the effects of microstructure on the macroscopic behavior and critical points on the local region.

REFERENCES

[1] Huang, Y., Yan, D., Yang, Z., & Liu, G. (2016). 2D and 3D homogenization and fracture analysis of concrete based on in-situ X-ray Computed Tomography images and Monte Carlo simulations. Engineering Fracture Mechanics, 163, 37–54.
[2] Yu, Q., Liu, H., Yang, T., & Liu, H. (2018). 3D numerical study on fracture process of concrete with different ITZ properties using X-ray computerized tomography. International Journal of Solids and Structures, 147, 204–222.
[3] Kim, H. T., Szilágyi, V., Kis, Z., Szentmiklósi, L., Glinicki, M. A., & Park, K. (2021). Reconstruction of concrete microstructure using complementarity of X-ray and neutron tomography. *Cement and Concrete Research*, *148*, 106540.
[4] Haralick, R. M., Sternberg, S. R., & Zhuang, X. (1987). Image analysis using mathematical morphology. IEEE Transactions on Pattern Analysis and Machine Intelligence,
[5] Kim, H. T., & Park, K. (2022). Computed tomography (CT) Image-based analysis of concrete microstructure using virtual element method. *Composite Structures*, *299*, 115937.
(4), 532-550.