

## Three-dimensional particle analysis during slaking behavior of Akita mudstone by photographic method. Part II

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## 1. Introduction

As a common engineering characteristic which is the main weathering mode from mudstones to soils, slaking behavior will seriously affect the strength of mudstone, and further cause engineering disasters. To study the slaking characteristic of different mudstone, slake durability test (Su *et al.*, 2020) and cyclic drying-wetting test (Sakai and Nakano, 2019) has been done. Besides, advanced observational techniques, including 2D images (Su *et al.*, 2020) and 3D CT analysis (Jiang *et al.*, 2014), have been used to observe the slaking process. Recent years, Akida mudstone has been used in road embankments of expressways in Japan. In this study, 3D particle models of mudstone were studied via photographic method during the cyclic drying-wetting test.

## 2. Materials, Equipments and Procedures

Fundamental properties of akita mudstone can be seen in Table 1. Several specimens with a total weight of 380g were used in this study. Fundamental properties of Akita mudstone and the method of transforming 2D images into 3D models have been introduced in the previous paper (Sun *et al.*, 2022). A camera with the resolution of 1920 × 1080 pixels and Nikon SMZ800 Microscope with the same resolution were used for obtaining 2D images of mudstone specimens during tests. The procedure of the test can be seen in Fig. 1, after 24h of wetting, the specimens dried in an oven with 110°C for 24 hours. These specimens were sieved with mesh sizes of 19, 9.5, 4.75, 2.00, 0.85, and 0.25mm after wetting and drying. Thereafter, weighing and photographing the fragments to obtain the particle size gradation and 2D images. 2D images were synthesized into 3D models and the specimens will be used in the next circle. It is worth noting that for small particles, a portion was selected for 3D analysis. There were seven cycles in total for this test.

Table 1 Fundamental properties of akita mudstone (from NEXCO RI)

Soil properties	Values
Soil particle density (g/cm <sup>3</sup> )	2.595
Density (g/cm <sup>3</sup> )	1.13
Natural water content (%)	48.6
Proctor compaction test	
Optimum moisture content (%)	51.3
maximum dry density (g/cm <sup>3</sup> )	1.031
Consistency limit	
Liquid limit (%)	80.5
Plasticity index	37.5

## 3. Test results and discussion

After obtaining 3D models of these specimens, a parameter Shape-3d ( $S_{3d}$ ) calculated by volume and surface area is used to evaluate the shape of mudstone particles. It is calculated by Eqn. 1 and for a sphere, it equals 1:

$$S_{3d} = \frac{A_{3d}^3}{V_{3d}^2} \times \frac{1}{36\pi} \quad (1)$$

where  $A_{3d}$  and  $V_{3d}$  is the surface area and volume of one mudstone particle respectively.

The results of  $S_{3d}$  in different circles can be seen in Fig. 2. For each circle, with the decrease of particle diameters, the value of  $S_{3d}$  will increase when particle size is large than 4.75mm and decrease after the peak in 9.5-4.75mm. This means that specimens with particle size between 9.5 and 4.75mm have the largest value of  $S_{3d}$ . In addition, the average peak values of curves decrease from 4 to 3 as the number of cycles increases. For the largest particles with the diameter larger than 19mm, the average value of  $S_{3d}$  decreases slightly from 2.5 to 2 as the number of cycle increases.

Slaking mechanisms can be summarized in three categories: (1) the air-breakage phenomenon, (2) differential swelling, and (3) dissolution of cement agents. Among them, the differential swelling has been explained by the swelling behavior of clay enriched area which is distributed unevenly in the specimens (Su *et al.*, 2020). However, another slaking

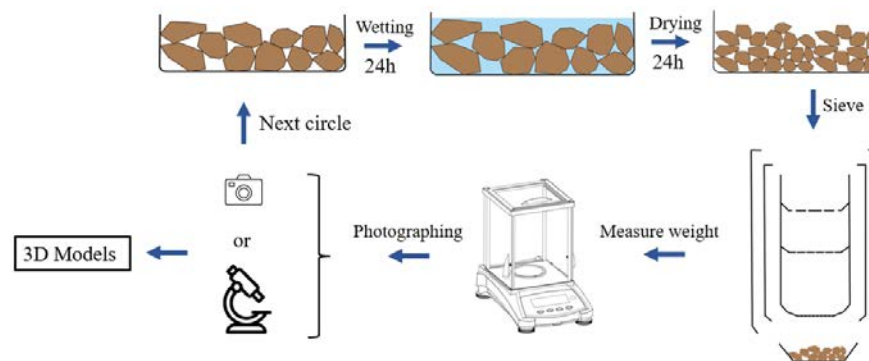


Fig. 1 Schematic view of cyclic drying-wetting test

Mudstone Slaking behavior 3-D model

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mechanism caused by differential swelling was observed in this experiment. Fig. 3 (a) shows a fragment is ready to slake from main body of the specimen. The slaking process can be seen clearly in Fig. 3 (b) and the slaked particle shows obvious layered structure (see Fig.3 (c)). The residual particles after slaking tend to be more spherical (see Fig. 3 (a) and (b)).

The process of slaking behavior caused by differential swelling can be seen in Fig. 4. The initial state of specimens is shown in Fig. 4 (a), as the water penetrates from surrounding (see Fig. 4 (b)), The mudstone of the outer layer expands, which cause it to separate from the inner drying body. A gap between main body and slaking particles were shown in Fig. 3 (c) and Fig. 4 (c). Finally, the outer shell-shaped structure of the specimen is broken due to internal force as shown in Fig. 4 (d). The remained specimens with particle size larger than 19mm tends to like a sphere, result in the decrease of  $S_{3d}$  of large particles in Fig. 2. The medium size slaked fragments with shell shape shown in Fig. 3 (c) results in the peak

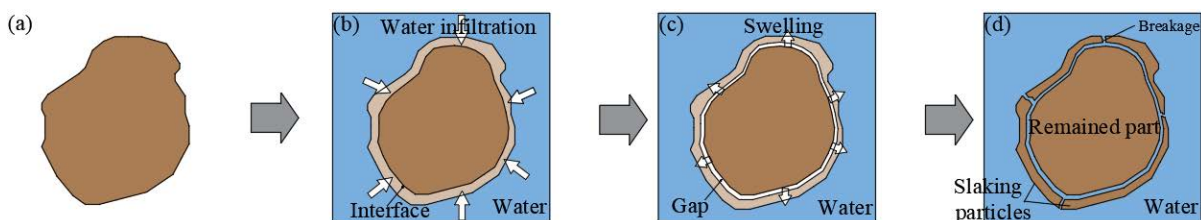


Fig. 4 Schematic view of slaking process

value of  $S_{3d}$  in Fig. 2. As the slaking behavior continues, the other two slaking mechanisms including air-breakage phenomenon and dissolution of cement agents may lead to the continued slaking of the shell-shaped particles, resulting in a decrease of peak values as shown in Fig. 2. However, the slaking mechanism of particles smaller than 4.75mm may not cause by differential swelling and does not show a shell shape, which leads to the reduction of  $S_{3d}$  value after peaks.

#### 4. Conclusions

Through the three-dimensional study on the shape of mudstone particles, this study revealed one of slaking mechanisms: the differential swelling caused by the uneven distribution of water in the process of water infiltration results in layered slaking behavior. During multiple slaking process, particle shape tends to be spherical.

Reference: (1) Jiang, Q., Cui, J. and Feng, X. (2014) 'Application of computerized tomographic scanning to the study of water-induced weakening of mudstone', pp. 1293–1301. doi: 10.1007/s10064-014-0597-5. (2) Sakai, T. and Nakano, M. (2019) 'ScienceDirect Effects of slaking and degree of compaction on the mechanical properties of mudstones with varying slaking properties', *Soils and Foundations*, 59(1), pp. 56–66. doi: 10.1016/j.sandf.2018.09.004. (3) Sun, D., Komine, H. and Wang, H. (2022) 'Three-dimensional particle analysis during slaking behavior of Akita mudstone by photographic method. Part I' The 57th annual meeting of the Japan national conference on geotechnical engineering. Kyoto, JAPAN. (4) Su, X., Tang, H., Huang, L., Shen, P. and Xia, D. (2020) 'The role of pH in red-stratum mudstone disintegration in the Three Gorges reservoir area, China, and the associated micromechanisms', *Engineering Geology*, 279(October 2019), p. 105873. doi: 10.1016/j.enggeo.2020.105873.

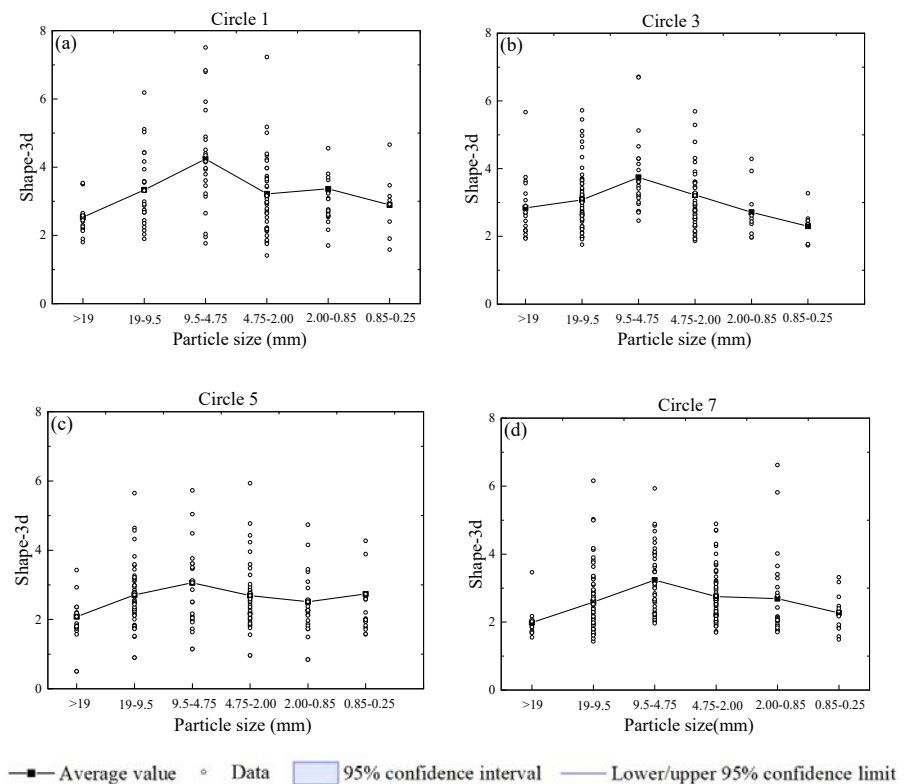


Fig. 2 Results of Shape-3d during slaking process

A fragment is ready to slake

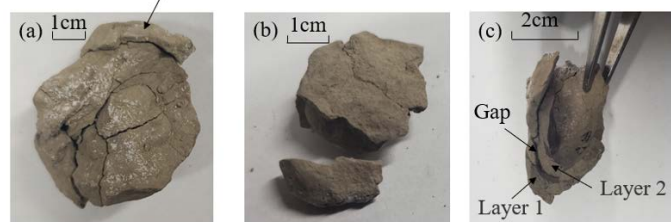


Fig. 3 Some typical particles during slaking process