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Effect of ultrasonic treatment on clay microfabric evaluation by atomic force microscopy

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A B S T R A C T

Researchers previously thought the only ways to investigate the microfabric of clayey soil were through a scanning electron microscope (SEM), a transmission electron microscope (TEM), an X-ray, and an optical microscope. However, in this research, ultrasonic equipment was used to disperse clayey soils (bentonite, illite, and kaolinite) for different lengths of time. After dispersion, an atomic force microscope (AFM) was employed to take three-dimensional (3D) photographs. While the samples were intact, AFM was able to take 3D photographs in different environments. The IA_P9_BUILD software was employed to analyze the data to obtain the angle of particle orientation and the particle size distribution. In this investigation, it was observed that with the use of an ultrasonic device with 30 KHz of power, bentonite, illite, and kaolinite reached a dispersion state after 12, 8, and 6 min, respectively.

1. Introduction

The angle of particle orientation has a significant effect on the mechanical properties of clayey soils [1]. The angle of particle orientation can be identified by studying the microfabric of clayey soil [2,3]. Soil response is known to be sensitive to material fabric, that is, the topology of the internal structure of the soil. Soil fabric is the geometric arrangement of particles within the soil mass [4]. In geomechanics research, fabric has been qualitatively described, and fabric changes have frequently been inferred from macroscale observations of soil responses: for example, the anisotropy of small-strain stiffness [5], the anisotropy of permeability [6], or a comparison of the mechanical responses of specimens prepared using different approaches [7].

On a small scale, the soil microfabric can be studied by looking at undisturbed samples under a scanning electron microscope (SEM) or it can be described under a high-resolution optical microscope in a thin section [8–13]. Soil fabric can be quantified using either scalar parameters or directional parameters. Examples of scalar measures of fabric include the coordination number, the void ratio distribution within the sample, and the contact index. Directional fabric can be measured using particle long-axis orientations or contact normal orientations, and the statistical approaches to analyze datasets of orientation vectors are relatively well-established [14–16]. Different kinds of soil fabrics indicate different sedimentary environments in which the soils were formed [17–19]. In addition, they could show the information of the different properties and distinct material compositions of soils. In general, the engineering properties of soil are connected closely to its structure and fabric [10]. In addition, they depend on the distance and angle between the clay particles [20,21]. The distance between two clay particles defines the porosity of the soil mass [4], whereas the angle

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between the two particles causes variations in the anisotropy of the soil mass, sensitivity, time-dependent deformation, and consolidation characteristics. Permeability is also strongly related to the type of microfabric [10,22]. In a flocculated microfabric, particles are exposed face-to-edge with identical possibilities beside each other [23]. In a dispersed microfabric, particles align face-to-face and are mainly parallel to each other. A schematic diagram of different microfabrics is shown in Fig. 1.

Particles within the clay mass can be studied in the form of a dispersed microfabric and a flocculated microfabric [4]. Flocculated microfabric refers to the particles of a sample that are oriented in all possible directions with equal probability and that form face-to-edge particle contact. Dispersed microfabric refers to the particles that are aligned in a preferential direction (mostly parallel to each other) and form face-to-face particle contact.

The problem with an SEM, transmission electron microscope (TEM), X-ray, or optical microscope is that these techniques change the identity (e.g., sample coating in SEM and sample preparation for X-ray Diffraction (XRD) and X-ray Fluorescence (XRF), etc.) of the soil. TEM is time consuming, and SEM and TEM equipment require expensive vacuum environments for proper operation. In this study, an atomic force microscope (AFM) is employed to study soil microfabric as a new method. AFM is able to capture two-dimensional (2D) and three-dimensional (3D) images with Z-information through colour intensity, providing the opportunity to obtain quantitative measurements of the microfabrics of cohesive soils using the IA_P9_BUILD software (NOVA P9 Image Analysis 3.5.0.2069-version: 1.9, released 23 July 2010) [24]. This technique has revealed more details. Using this technique, features of the soil fabric can be captured. One of the greatest advantages of this device over others is that samples can be prepared with ease and no damage or irreversible change occurs to the soil. The fact that AFM can capture images in any condition (vacuum, humidity, and air) is what keeps the soil intact. Sachan used AFM to study the microfabric of cohesive soil, as well as used Calgon for the dispersion of the clay samples [25].

In the current research, many clayey soil samples (bentonite, illite, and kaolinite) were prepared using different concentrations of a dispersing agent (ultrasonic) to obtain the angle of particle orientation using the information acquired through AFM images.

In this investigation, an ultrasonic device was used for dispersion. The method that produces the most complete dispersion of a soil sample is generally the more acceptable method. However, the chemical treatment and mechanical work done to the soil are dictated by somewhat arbitrary decisions, so there is no absolute size distribution for a given sample. However, chemical treatment can destroy and dissolve some soil minerals. Physical treatments are also used, but the standardization of treatment and adequate testing of specific methods are needed, as the very process of separation by mechanical or ultrasonic means can fragment the individual particles into further subunits.

Ultrasonic dispersion is a widely used method to disaggregate and disperse soil aggregates. Aggregates and particles of different sizes may be fractioned and used for further physical or chemical analyses without the prior use of chemical agents [26,27]. Ultrasonic waves are emitted into water containing the soil aggregates, and cavitation bubbles are generated. High pressure occurs when cavitation bubbles collapse, which promotes the disaggregation and dispersion of soil aggregates. Much work has been done to test the ultrasonic dispersion of soils, but no standard procedures have been adopted [28–33]. An initial concern with this method of dispersion was the possible destruction of primary particles, but Saly reported that ultrasonic vibrations did not destroy the crystalline lattice or break down the primary grains [29]. Edwards and Bremner investigated the use of ultrasonic dispersion in the absence of a dispersing agent [28]. For a mineralogical analysis, ultrasonic dispersion was preferred, as dispersion was achieved without pre-treating the soil or adding a dispersing agent. The following are the summarized advantages of ultrasonic dispersion [28]:

1. The resultant suspension is stable; hence, flocculation does not occur during sedimentation.
2. The method works well for dispersing calcareous soils, organic soils, and soils with high clay content.
3. Ultrasonic dispersion does not destroy organic matter.

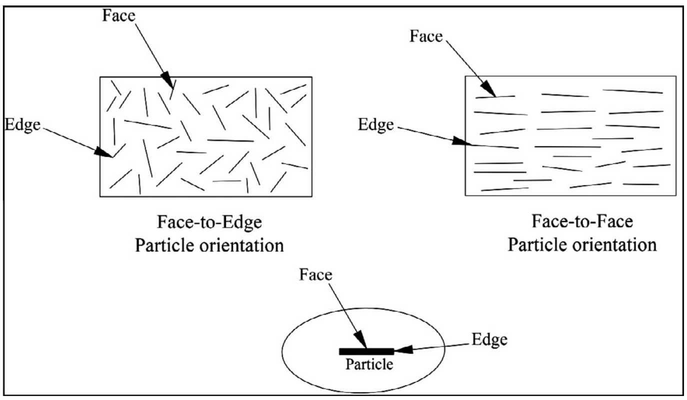

Fig. 1. Schematic diagram of a clay specimen with different microfabrics and the required direction.