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Influence of Particle Shape of Hydrophobic Granular Materials on Shear Strength

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ABSTRACT

Geo-hazards such as wild fire and oil spillages can change the water-wettable(hydrophilic) soils to water-repellent(hydrophobic) soils. The surface modification originated from the geo-hazards may influence the shear strength of hydrophobic soils. The objective of this study is to evaluate the effect of particle shape on the shear strength of hydrophobic soils. For the surface modification of particles, glass beads and crushed sands are coated through a silica silanization reaction. The direct shear tests are carried out for the comparison of the shear strength between round glass beads and angular crushed sands. Experimental results show that, regardless of particle shape, the shear strength of hydrophobic soils is smaller than that of hydrophilic soils. In addition, in the case of crushed sands, the difference of shear strength between hydrophilic and hydrophobic soils is greater than that of shear strength in the specimens composed of glass beads. This study suggests that the particle shape is an important factor contributing to the shear strength of hydrophobic soils.

1. INTRODUCTION

Natural soils is generally water-wettable(hereafter hydrophilic). However, wild fire and oil spillages can change the natural soils to water-repellent(hereafter hydrophobic) soils. The hydrophobic soils tend not to allow water to infiltrate into the subsurface ground. The hydrophobicity of natural soils increases overflow, reduces evaporation, and generates a preferential flow (Ritsema and Dekker 2003).

Many researches have been carried out for the verification of friction properties according to the hydrophobicity. Burton and Bhushan (2006) showed that for the hydrophobic surface with 50% relative humidity the coefficient of friction reduces due to the decrease in the real area of contact. Byun et al. (2012) demonstrated that the shear strength of hydrophobic glass beads is lower than that of hydrophilic ones. However, no studies have been carried out for the evaluation of the particle shape effect on the

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shear strength of hydrophobic granular media.

This paper presents a comparison of the shear strength between hydrophobic media and hydrophilic one prepared from round glass beads and angular crushed sands. The conventional direct shear tests were performed to evaluate the shear strength. Then, experimental results were analyzed and discussed about the shear strength of hydrophobic granular media according to the particle shape.

2. EXPERIMENTAL STUDIES

2.1. Specimen Properties

Round glass beads and angular crushed sands, as shown in Fig. 1, were used to investigate the effect of particle shape. To minimize the effect of particle size, the specimens passed through no. 50 sieve and remained on no. 80 sieve. Median diameters(D_{50}) of glass beads and crushed sands were 0.25mm. The maximum and minimum void ratio were 0.76 and 0.61 in glass beads, and 1.04 and 0.64 in crushed sands.

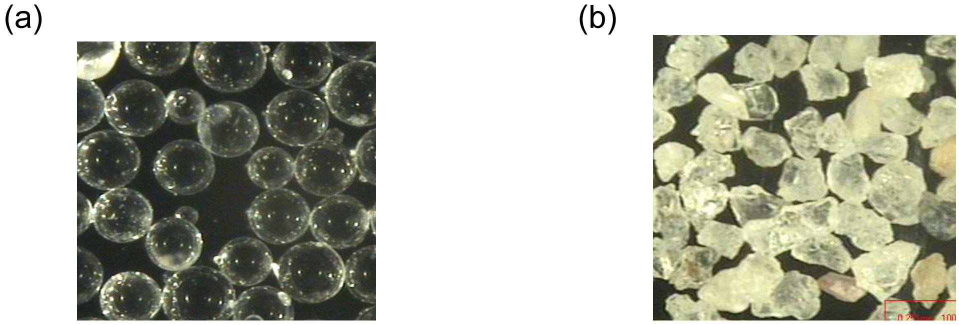

Fig. 1. Microscopic images of the specimen: (a) glass beads; (b) crushed sands.

2.2. Specimen Preparation

The silica silanization was adopted for the surface modification of hydrophilic particles as follows (Da Re 2000).

$$\equiv Si — OH + C_8H_{17}Si(OC_2H_5)3 \Rightarrow \equiv Si — O — Si(OC_2H_5)_2C_8H_{17} + C_2H_5OH \quad (1)$$

The reactive solution was made with 10% n-octyltriethoxysilane and 90% isotropy-alcohol by weight. The hydrophilic particles were immersed in the reactive solution at 20^{o}C for 48 hours and then dried at 90^{o}C for 24 hours. Finally, the coated glass beads and crushed sands as hydrophobic particles were separated from the hydrophilic particles.

The dry condition of the specimens was adopted to investigate the effect of the friction according to the particle shape of hydrophobic granular media. Each specimen was prepared in 10 layers of equal mass by the tamping method. The initial void ratio of the glass beads was fixed at e_o=0.61 due to the round particle shape, while that of the crushed sands was fixed at e_o=0.65 due to the angular particle shape.

2.3. Test Procedures

The conventional direct shear test was carried out to evaluate the shear strength characteristics of the hydrophobic glass beads and crushed sands. First, the specimens obtained from the silanization reaction were prepared with the initial void ratio. Then, the normal stresses of 1, 10, 20, 40, 80kPa were applied on the top of the specimens. After the vertical settlement was completed, the specimens was sheared with the rate of 0.5mm/min up to the horizontal displacement of 6mm.

3. EXPERIMENTAL RESULTS

The shear stresses versus horizontal displacements in the hydrophobic and hydrophilic glass beads are plotted in Fig. 2. The shear stresses increase with the increase in the normal stress in both specimens. In addition, the maximum shear stresses(peak shear strengths) in the hydrophobic specimens are lower than those in the hydrophilic specimens.

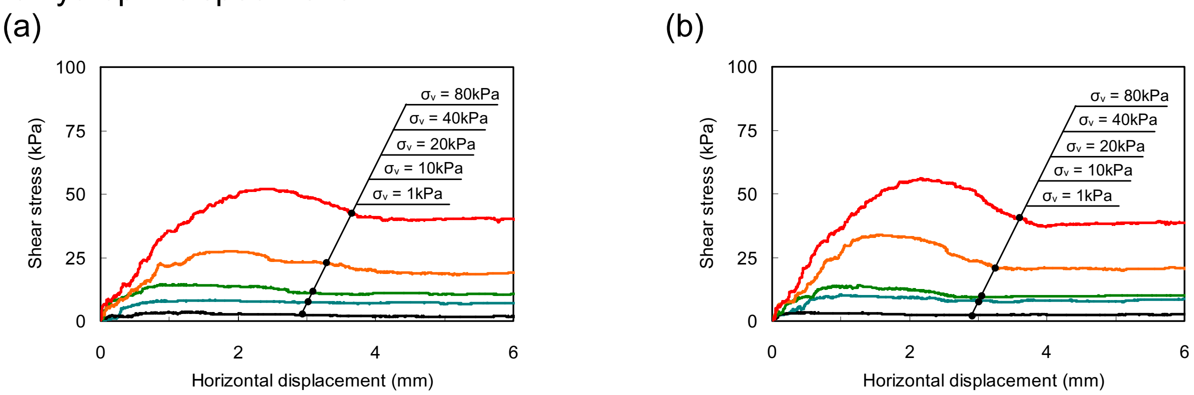

Fig. 2. Stress-displacement curves of glass beads: (a) hydrophobic; (b) hydrophilic.

In the hydrophobic and hydrophilic crushed sands, the shear stresses versus horizontal displacements are plotted in Fig. 3. As the glass beads, the shear stresses increase with the increase in the normal stress and the maximum shear stresses in the hydrophobic specimens are lower than those in the hydrophilic specimens.

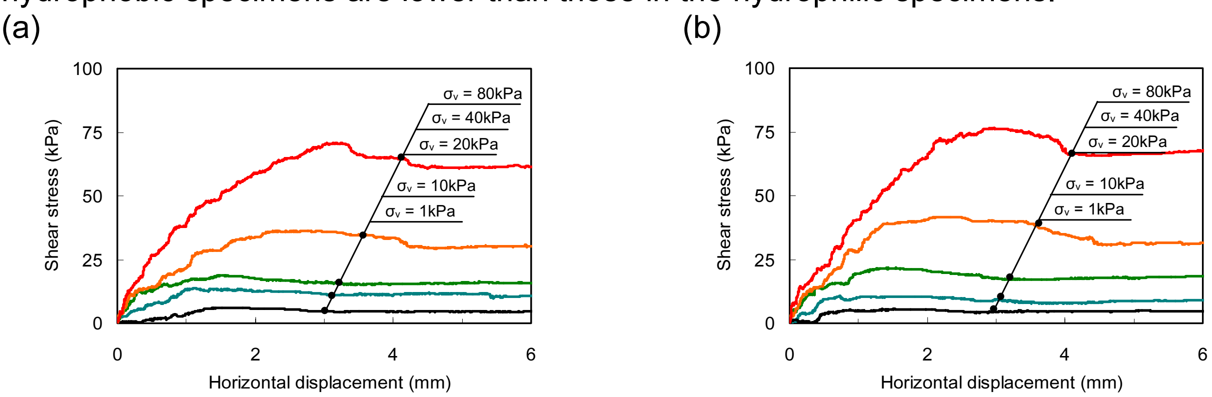

Fig. 3. Stress-displacement curves of crushed sands: (a) hydrophobic; (b) hydrophilic.

4. DISCUSSIONS

This study compared the shear strength of hydrophobic specimens according to the particle shape as shown in Fig. 4. Fig. 4(a) shows that the internal friction angles at peak state are 32° and 34 ° for the hydrophobic and hydrophilic glass beads, respectively, while the internal friction angles are 39° and 43° for the hydrophobic and hydrophilic crushed sands, respectively. The results demonstrate that the angular particle shape of the crushed sands produces the greater difference of shear strength between hydrophobic sands and hydrophilic sands. Fig. 4(b) shows that the internal friction angle at critical state is 26 ° for the hydrophobic and hydrophilic glass beads, while the internal friction angles are 38° and 40° for the hydrophobic and hydrophilic crushed sands, respectively. The results mean that, by the surface modification, the reduction of shear strength in angular particle is greater than that in round particle.

(a) (b)

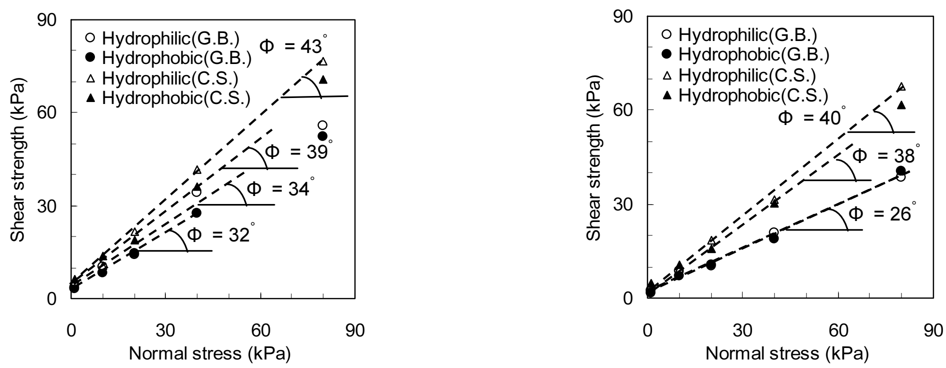

Fig. 4. Comparison of shear strength: (a) peak state; (b) critical state.

5. CONCLUSION

This shear strength characteristics of hydrophobic and hydrophilic media have been investigated with glass beads and crushed sands. The reaction of silanization is used to produce the hydrophobic specimens. The conventional direct shear tests are performed in the dry condition. Experimental results show that the internal friction angles of hydrophobic specimens are lower than those of hydrophilic specimens regardless of the particle shape. At critical state, the internal friction angle of the hydrophobic crushed sands is slightly lower than that of the hydrophilic crushed sands, while those of hydrophobic and hydrophilic glass beads are similar. These results demonstrate that, in the soils composed of angular particles, the reduction of shear strength should be considered when the natural soils are changed into the hydrophobic soils.

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