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Effects of biopolymer on the unconsolidated-undrained static triaxial test behavior of sand

Effets du biopolymère sur le comportement du test triaxial statique non consolidé-non drainé du sable

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ABSTRACT: Gel-type biopolymers have been introduced as new environmentally friendly soil binders that have shown substantial strengthening effects in laboratory experimental programs. Although the shear resistance of gel-type biopolymer treated sands has been verified with direct shear tests and uniaxial compressive tests, there has been no attempt to examine shear behavior under different confining stress conditions. Therefore, this study investigates gel-type biopolymer treated sands with laboratory triaxial tests to describe shear behavior with isotropic confinement taken into account. In this study, sand is treated at 0.5% and 1.0% to soil content in mass (m_b/m_s), and xanthan gum which is a gel-type biopolymer have been used. It is assumed that the shear behavior of the gel-type biopolymer treated sands differs according to curing conditions (initial and dried), due to biopolymer hydrogel matrix formation and accompanying gel strength variation.

RÉSUMÉ: Les biopolymères de type gel ont été introduits en tant que nouveaux liants des sols respectueux de l'environnement qui ont montré des effets de renforcement substantiels dans les programmes expérimentaux en laboratoire. Bien que la résistance au cisaillement des sables traités au biopolymère de type gel ait été vérifiée par des tests de cisaillement direct et des tests de compression uniaxiaux, aucune tentative d'examen du comportement au cisaillement dans différentes conditions de contrainte de confinement n'a été effectuée. Par conséquent, cette étude examine les sables traités avec un biopolymère de type gel avec des tests triaxiaux en laboratoire pour décrire le comportement au cisaillement en tenant compte du confinement isotrope. Dans cette étude, le sable est traité à 0,5% et 1,0% de la masse (m_b/m_s) du sol, et la gomme de xanthane, qui est un biopolymère de type gel, a été utilisée. On suppose que le comportement au cisaillement des sables traités avec un biopolymère de type gel diffère selon les conditions de durcissement (initiale et séchée), en raison de la formation de matrice d'hydrogel de biopolymère et de la variation de résistance du gel qui l'accompagne.

Keywords: Biopolymer, sand, triaxial test, sand

1 INTRODUCTION

Soil stabilization has been widely utilized at construction sites and in social infrastructure. From bitumen to natural pozzolan materials such as volcanic ash, many materials have been evaluated in atteMmpts to develop a more effective soil stabilizing material (Chang et al. 2016). Following the Industrial Revolution, cement and gypsum has been broadly researched and used at many construction sites due to its high cost-effectiveness. However, with climate change a growing concern, there is a need to develop an alternative solution. Carbon emission charges for geotechnical engineering have reached approximately 2% based on cement usage (Chang et al. 2016), and many researchers have suggested alternative materials (Al Qabany and Soga 2013; Horpibulsuk et al. 2011; Kamon and Nontananandh 1991; Kaniraj and Havanagi 2001; Mortensen and DeJong 2011).

The gel-type biopolymer has recently been addressed as a new environmentally friendly construction material due to its biodegradation characteristics and low greenhouse gas emissions (Chen et al. 2013; Kavazanjian et al. 2009; Kulshreshtha et al. 2017). Many researchers have studied the feasibility of gel-type biopolymer treatment as a new form of soil stabilization (Chang et al. 2016; Chen et al. 2016; Latifi et al. 2016; Rashid et al. 2017).

However, most recent studies have focused on strengthening effects without regarding practical factors. Gel-type biopolymer treated soils have mainly been evaluated through laboratory uniaxial compressive tests and direct shear tests (Cabalar et al. 2017; Chang and Cho 2012; Fatehi et al. 2018; Hataf et al. 2018; Lee et al. 2017). Though the degree to which the soils have been reinforced can be verified, the treatments' effectiveness under practical conditions has not been analyzed. The exact effectiveness for practical implementation of gel-type biopolymers cannot be estimated without considering critical in-situ factors.

Therefore, this study verifies shear behavior of gel-type biopolymer treated soil via a laboratory triaxial system. As one of main in-situ factors is confinement pressure, various confinement conditions are applied in our experiments. Previous studies have indicated that gel-type biopolymers are affected by water content (content) of biopolymer hydrogels. The shear behavior of gel-type biopolymer treated soil differs based on the soil's hydraulic condition (e.g., initial, dry, and re-submerged). To examine this behavior in a confined situation, gel-type biopolymer treated soil is tested in both initial and dry states in this study. In addition, the content of gel-type biopolymers is considered as a critical affecting factor; therefore, two different content conditions are applied in this research.

2 MATERIALS AND METHOD

2.1 Materials and Method

<u>Sand</u>

The soil used in this study is Sydney sand. This subangular quartz sand is classified as SP under the Unified Soil Classification System. Relevant information on this sand is shown in Table 1.

Table 1. Properties of Sydney sand

e_{max}	e_{min}	D_{50}	C_u	C_c	G_s	USCS
0.92	0.6	0.36	1.18	0.96	2.60	SP

<u>Biopolymer</u>

Xanthan gum is used to make cemented specimens. This polysaccharide-type biopolymer is composed of two glucose units, two mannose units, and one glucuronic acid unit. The repeated structure consists of the main chain and a trisaccharide side chain. The main chain is made by linking beta-D-glucose units at positions 1 and 4. The side chain containing D-glucuronic acid and two D-mannose units is attached at the O-3 position of glucose in the main chain (García-Ochoa et al. 2000).

2.2 *Sample preparation*

Biopolymer powder is dissolved into deionized water (w/c = 20% to soil mass) to prepare a biopolymer solution. The biopolymer solution content is 0.5% and 1.0% by mass ratio (m_b/m_s). These biopolymer solutions are mixed with sand (a process called "wet mix" herein). Homogenously mixed biopolymer treated sands are prepared in their dry and initial states. Drying in a 50°C oven proceeds for 14 days without demolding, and the specimen itself is additionally dried for 14 days after demolding. Samples of initial states are tested without any drying procedure after wet mix. Contributions are accepted on the understanding that the paper is original and has not been published before.

2.3 *Test procedue*

Test samples are prepared using a split mold 50 mm in diameter and 100 mm in height. Porous stones are placed above and beneath the samples, where entire samples are mounted within a rubber membrane to isolate them from the pressurized chamber fluid. The experimental apparatus is depicted in Figure 1. A computer-controlled triaxial device is connected to the experimental system. Digital volume/pressure controller (GDS) is used to measure pressure and volume changes in the chamber/pore fluid. The external LVDT is attached on the top of the chamber to trace axial displacement. The confinement conditions are 50, 100 and 200 kPa, and the applied strain rate is 0.1 mm/min.

<u>Consolidated Drained Test</u>

For untreated soil, negative pressure is applied to derive self-standing force, then the wet mounting method from ASTM D7181 is implemented (ASTM 2011). After assembly, the specimens are saturated with de-aired water and flushed with CO_2. Thereafter, a back-pressure of 500 kPa is applied until the B value has reached 0.9. After saturation, consolidation proceeds and the specimens are sheared.

<u>Unconsolidated Undrained Test</u>

The initial-status specimens are directly mounted on the apparatus; however, no negative pressure is applied because these samples, due to their cohesion derived from the hydrogel biopolymer, can maintain their shape without any pressure. After the chamber pressure is applied, shearing commences. Dried specimens can stand up without negative pressure because of their sturdy biofilm. In maintaining and testing under dry conditions, no saturation is performed on dried specimens. Therefore, the shearing is performed directly after consolidation.

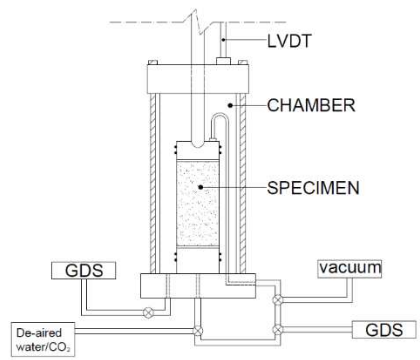

Figure 1. Laboratory triaxial testing system

3 RESULTS AND ANALYSIS

As shown in Figures 2a and 2b, peak strength rises as confinement pressure is increased in the case of untreated sand. Specifically, peak strength (σ_1) rises from 540 kPa to 1109 kPa when minor principle stress (σ_3) is increased from 100 kPa to 200 kPa. Results show a cohesion value of 18.3 kPa and a friction angle of 41.0º. Therefore, the cohesion is negligible and it can be regarded as a cohesionless soil.

Gel-type biopolymer treated sand in its initial state exhibits residual shear behavior, as shown in Figures 3a and 3b. Regardless of biopolymer content, peak and residual shear strength are enhanced as confinement stress is increased. For instance, deviator stress rises from 280 kPa to 440 kPa when minor principle stress (σ_3) is increased from 50 kPa to 100 kPa in the case of 0.5% gel-type biopolymer treatment. However, there is a reduction in shear strength with higher gel-type biopolymer content under the same confinement conditions. For example, at a confinement pressure of 100 kPa, peak deviator stress is reduced to 310 kPa when gel-type biopolymer content is 1.0%, whereas the figure is 440 kPa at 0.5% gel-type biopolymer content under the same confinement pressure.

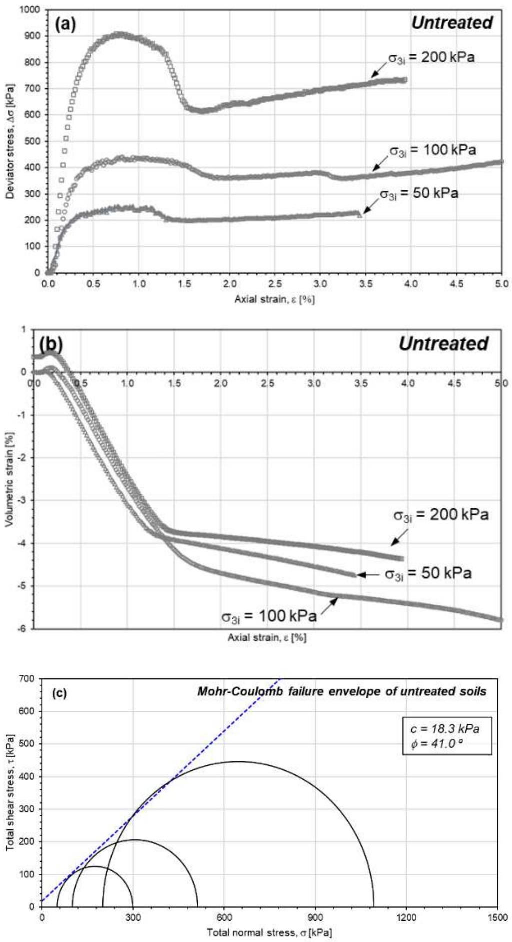

Figure 2. Experimental results of untreated soil by consolidated undrained triaxial testing. (a) stress-strain curve; (b) volumetric strain-axial strain curve; (c) Mohr-coulomb diagram.

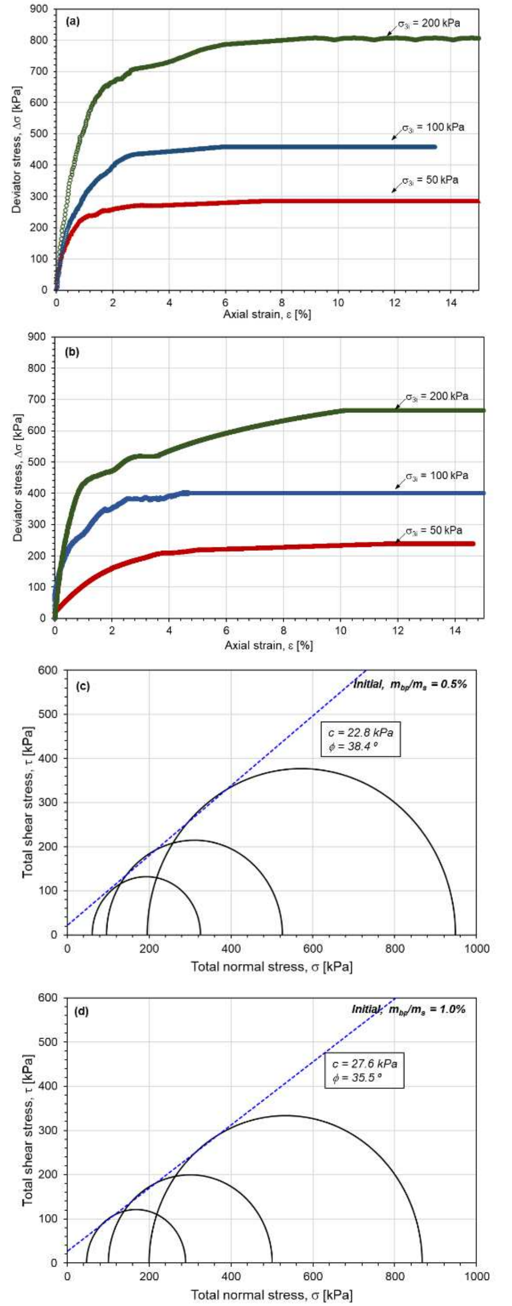

Figure 3. Experimental results of biopolymer treated soil by unconsolidated undrained triaxial testing, at initial status. (a) stress-strain curve; (b) volumetric strain-axial strain curve; (c) Mohr-coulomb diagram (m_b/m_s = 0.5%); (d) (m_b/m_s = 1.0%).

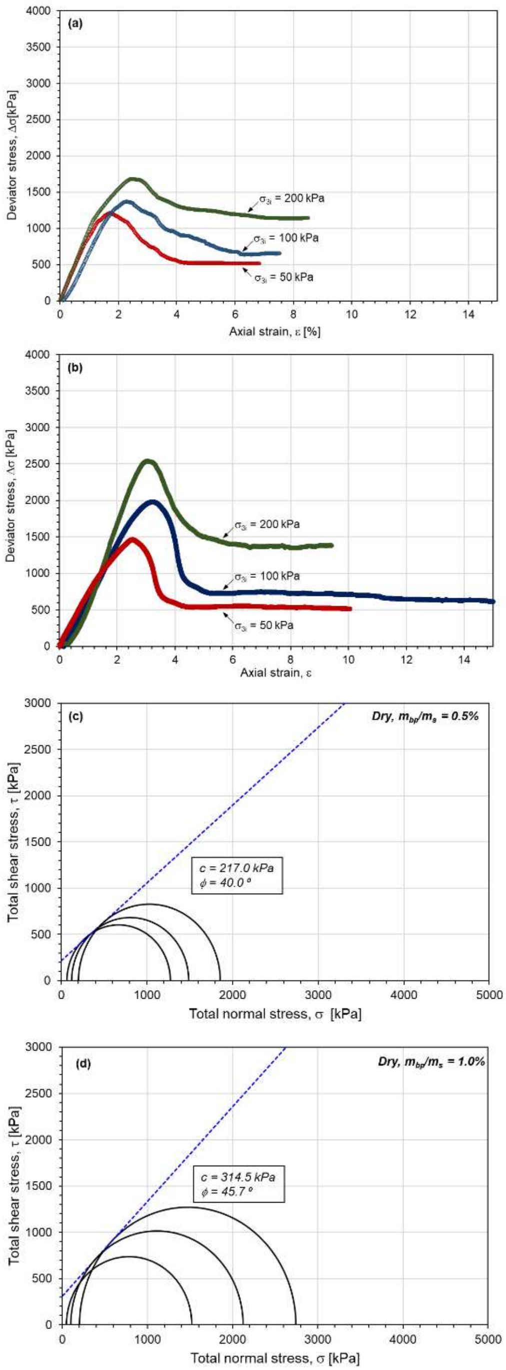

Figure 4. Experimental results of biopolymer treated soil by unconsolidated undrained triaxial testing, at dry status. (a) stress-strain curve; (b) volumetric strain-axial strain curve; (c) Mohr-coulomb diagram (m_b/m_s = 0.5%); (d) (m_b/m_s = 1.0%).

Consequently, the friction angle decreases and cohesion increases with increased density of gel-type biopolymers within specimens.

When specimens are sufficiently dried, shear strength is significantly enhanced compared to initial status, as shown in Figures 4a and 4b. In addition, the peak strength of gel-type biopolymer treated sand becomes higher as confinement pressure is increased comprehensively. Moreover, the strain value at peak strength tends to increase as confinement pressure rises, although peak shear strength values at a biopolymer content of 1.0% are similar under confinement conditions of 100 kPa and 200 kPa. Accordingly, the friction angle and especially the cohesion value significantly increase as the biopolymer content is made thicker.

4 DISCUSSION

The laboratory experiment results show that the effectiveness of gel-type biopolymers is still valid under certain confining pressures. Although there is a tendency for peak strength to increase as confinement pressure (minor principle stress) rises, this differs according to the water content of gel-type biopolymer treated sand.

Under initial conditions, peak strength is lower when the content of gel-type biopolymers is higher, the reason being that the interrelationship is not established directly after wet mix, and biopolymers remian as hydrogel status initially. As a result, the friction angle decreases and cohesion is enhanced as the gel-type biopolymer content densifies. In other words, the effect on the friction angle is dominant, although enhancement of cohesion in the soil also occurs when the gel-type biopolymer is in its initial state.

In the case of dried specimens, peak strength increases, as confinement pressure rises and the gel-type biopolymer content is made denser. Consequently, cohesion, rather than the friction angle, is substantially enhanced when the gel-type biopolymer is dried. This is because of developed cohesion owing to sturdy biofilm matrix between soil particles, which increases resistance to external force. That is, the effectiveness of gel-type biopolymers is mainly results to significant increment of inter-particle cohesion of soils, especially for sands. Meanwhile, peak strength shows a lower axial strain value when a higher confinement pressure is applied (such as when soil treated at a 1.0% gel-type biopolymer content is tested under 100 kPa and 200 kPa confinement conditions), because the biofilm matrix might reach the critical (maximum) level of resisting force against external force. Therefore, the resisting energy can be regarded as approximately the same value at both 100 kPa and 200 kPa confinement conditions when the gel-type biopolymer content is 1.0%.

The strengthening effect is substantial even under confined conditions, although it is diminished at higher gel-type biopolymer contents than that found in the initial state. In other words, if the biofilm matrix is well developed between soil particles, the strengthening by gel-type biopolymers is effective at shallow depth conditions.

In addition, it is obvious that the ductile behavior is shown when the biopolymer is treated. In other words, the biopolymer has a high potential to mitigate the failure at construction sites. Moreover, the residual strength displays higher values at any dry conditions than corresponding untreated values, which means that the biopolymer can resist longer against external force when the biopolymer film matrix is well established.

5 CONCLUSION

In this study, the effectiveness of gel-type biopolymer treatment under confined conditions is researched via laboratory triaxial testing. Our findings show that peak strength is enhanced under higher confinement conditions and, once a biofilm matrix is developed, with higher contents of gel-type biopolymers. Cohesion is significantly enhanced with higher gel-type biopolymer content because of the interparticle biofilm matrix which is developed during the drying period. However, the degree of strengthening effectiveness changes when specimens are tested directly after wet mix (i.e. in the initial state). Although cohesion increases slightly with higher gel-type biopolymer content due to the cohesive characteristics of biopolymers in a hydrogel state, the friction angle decreases due to no relationship between soil particles and biopolymer hydrogel.

As it is deduced that the biopolymer is substantially susceptible to water in this study, the biopolymer is effective when the biopolymer is sufficiently dried. However, once the biopolymer film matrix is developed, the peak strength as well as the ductility and residual strength are enhanced.

6 ACKNOWLEDGEMENTS

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