CONCLUSIONS AND RECOMMENDATIONS

This study explored the use of metakaolin-based geopolymer for evaluating the swell-shrink behavior of a native North Texas soil. The soil was mixed with the K431 GP mix at a ratio of 8% (by weight) dry GP to dry soil. Shrinkage tests show that geopolymer treatment of soil is efficient in reducing shrinkage, without developing cracks. Swell tests show that the swell potential of the treated soil is mitigated within acceptable limits. To summarize, GP treatment of soils reduce the swell-shrink potential of soils significantly, which is a major concern for high PI soils. Therefore, there is potential for wide-scale application of GP as a sustainable soil stabilizer for high PI soils. Further study is recommended to evaluate the effects of dry GP-to-dry soil ratio, GP composition, processing methods, and alkali-activator on the engineering properties of GP treated subgrade soils. Furthermore, durability studies as well as sustainability metrics and life cycle cost analysis studies would be useful in practical implementation of this soil stabilization method.

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Tri-Axial Shear Behavior of Xanthan Gum Biopolymer-Treated Sand

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ABSTRACT

Recently, soil strengthening using gel-type biopolymers have been attempted by many researchers. However, most previous studies have been conducted by focusing on feasibility of biopolymers as a new soil binder with lack of in situ considerations (e.g., confinement and strain-stress related variation). This study aims to investigate the shear behavior of xanthan gum-treated sand under different in situ confinement conditions. Laboratory tri-axial test is performed under three different confinement conditions (σ_3=50 kPa, 100 kPa, 200 kPa) with different xanthan gum biopolymer contents (m_{bp}/m_s=0.5%, 1.0%, 2.0%). It is revealed that high shear strength is developed when the biopolymer film matrix is established within the pore space when the biopolymer is thoroughly dried in the laboratory (oven). The strengthening effect by biopolymer film is substantial although its enhancement is varied according to xanthan gum contents and confinement conditions.

INTRODUCTION

Near surface ground improvement has been widely performed in geotechnical engineering practices, where new materials and methods have been actively introduced to the field by numbers of research (Ahmed et al. 2011; Chen 2006; Han 2015; van Paassen et al. 2010; Van Paassen 2009). Several types of chemical soil stabilizers including lime, cement, and silica-based gel have been commonly used in various ground improvement practices. However, as the importance of environment preservation and sustainability raises, demands on new construction materials have motivated research and development of environmentally-friendly materials nowadays (Chang et al. 2016).

Researchers have focused on the natural environment of soils, where microbes and fungi exist and actively produce excrements which provide inter-particle bonding substances in soils. Microbial induced calcite precipitation (MICP) has been introduced improve mechanical properties of soils, especially the strength of sand soils (Cabalar et al. 2016; DeJong et al. 2006; Lin et al. 2016; Montoya and DeJong 2015; Mujah et al. 2017; Pham et al. 2013; Van Paassen 2009). However, the effectiveness of MICP treatment shows high sensitivity to in-situ conditions (porosity, temperature, moisture content) although precipitated calcite renders recognizable soil strengthening.

Meanwhile, microbial biopolymer treatment has been attempted to overcome limitations of MICP in terms of time deduction and qualitative soil treatment for adequate practical implementation. Microbial polysaccharides (i.e., biopolymers) have been actively attempted to be a new bio-soil material by numbers of research (Cabalar et al. 2018; Cabalar and Canakci 2011; Chang and Cho 2012; Chang et al. 2018; Chang et al. 2015; Chang et al. 2015; Kavazanjian et al. 2009; Kulshreshtha et al. 2017).

Biopolymer treatment for soil strengthening becomes comparable to conventional stabilizers such as cement, and gypsum in strengthening efficiency and low CO_2 footprint perspectives (Chang et al. 2016). In details, biopolymer contributes to decrease CO_2 emission by reducing the usage of cement, which is a high CO2 emitting material by contributing almost 8% of the global CO_2 emission (Le Quéré et al. 2018). On average, CO_2 emission related to cement usage in geotechnical engineering practices is estimated to take 0.2% of the global CO_2 emission (Chang et al. 2016). Moreover, biopolymer production does not show high CO_2 emission due to its carbon capture during biopolymer production.

It is necessary to consider in-situ affecting factors in order to enhance effectiveness of biopolymer treatment. Xanthan gum has been introduced to be a promising soil binder due to its high strengthening (Cabalar et al. 2017; Chang et al. 2015) and shear strength (Lee et al. 2017) behaviors. However, previous studies mostly focused on feasibility validation and basic strengthening behavior investigation. Especially, in-situ three-dimensional stress conditions consideration has not been performed adequately. Thus, this study aims to evaluate the shear strength properties of xanthan gum-treated sands under different confining stress conditions ($\square_3$ = 50 kPa, 100 kPa, 200 kPa) and biopolymer contents (m_{bp}/m_s = 0.5%, 1.0%, 2.0%).

MATERIALS AND METHOD

Sand: Sydney sand which is classified as poorly graded soil (SP) has been used in this study. Sydney sand is representative quartz sand with subangular particles. Sydney sand has maximum void ratio (e_{max}) of 0.92, minimum void ratio (e_{min}) of 0.6, D_{50} of 0.36, coefficient of uniformity (C_u) of 1.18, coefficient of curvature (C_c) of 0.96, and specific gravity (G_s) of 2.6 g/cm^3 (Payan et al. 2016).

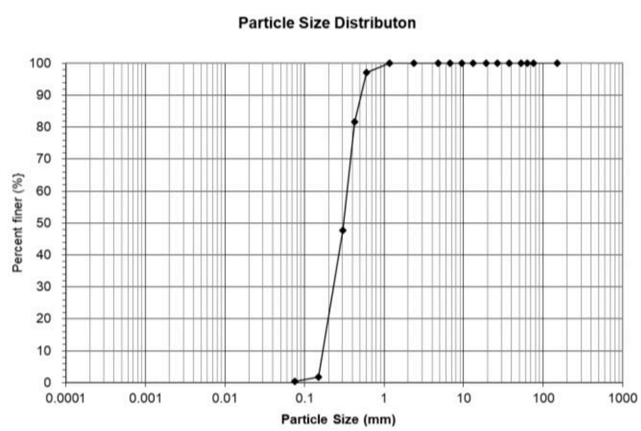

Figure 1. Particle size distribution curve of Sydney sand.

Xanthan gum biopolymer: Xanthan gum is an anionic polysaccharide produced by the plant-pathogenic bacterium *Xanthomonas campestris* (Chang et al. 2015). Xanthan gum is a hetero-polysaccharide which has a primary structure consisted of two glucose units, two mannose units, and one glucuronic acid unit (Becker et al. 1998). The beta-D-glucose units in a primary structure has connection at 1 and 4 positions, therefore, it consists main chain. Two mannose units and one glucuronic acid unit are linked to the main chain by the connection toward glucose at O-3 position (García-Ochoa et al. 2000).

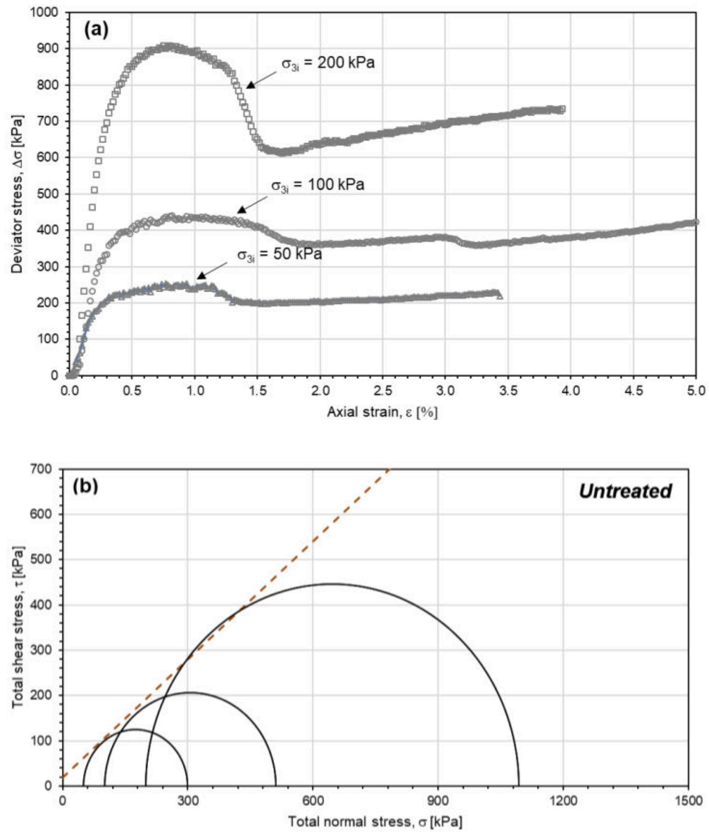

Figure 2. Shear behavior of untreated sand: (a) stress-strain relationship, and (b) failure envelope under three different confinement conditions.

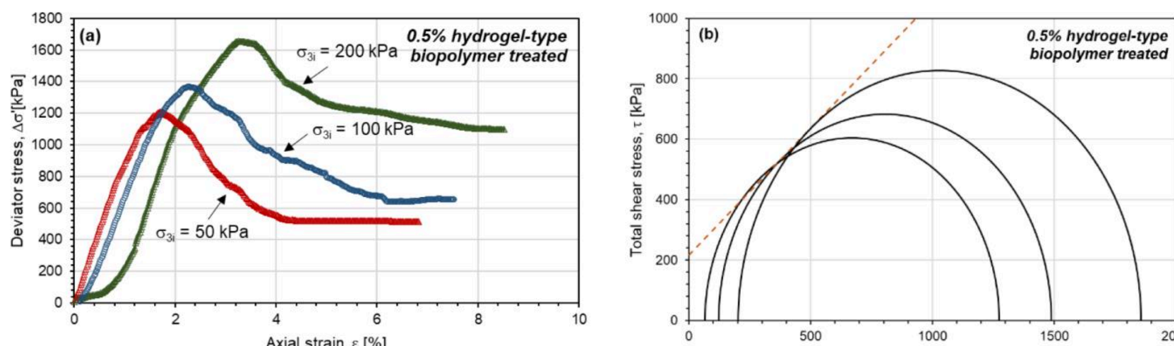

Figure 3. Example of strain-stress relationship according to confinement variation at 0.5% xanthan gum-treated condition (m_{bp}/m_s) at 50, 100, 200 kPa confinement conditions. (a) Axial strain-deviator stress. (b) Mohr-circle diagram.

Xanthan gum-treated sand: The xanthan gum-treated sand specimens are prepared by xanthan gum biopolymer and Sydney sand with wet-mixing method. In detail, hydrogel solution is mixed with sand at 20% water content condition using a laboratory mortar mixer. Thereafter, homogeneous biopolymer hydrogel-treated soil specimens were molded into a cylindrical shape with 50-mm-diameter and 100-mm-height. The xanthan gum treatment percentage is differed as 0.5%, 1.0%, and 2.0% (m_{bp}/m_s). All specimens were dried in an oven at 70°C for 14 days to ensure sufficient biopolymer biofilm matrix formation between soil particles through the dehydration of xanthan gum hydrogels (Chang and Cho 2018; Chang et al. 2015). After drying, specimen molds were dismantled and the dimensions and mass of each sample were measured. The average relative density of xanthan gum-treated sand specimens show $D_r = 67\%$.

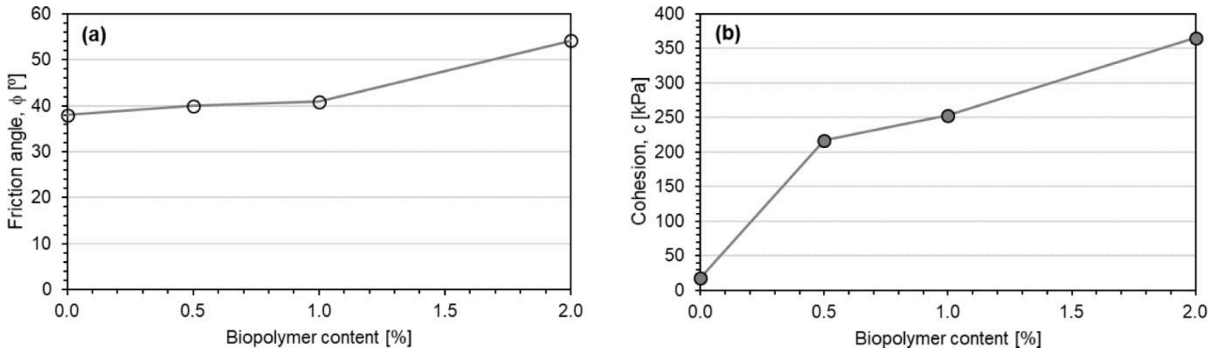

Figure 4. The effect of xanthan gum content related to friction angle (a) and cohesion (b).

Laboratory triaxial test: Both untreated (natural) and xanthan gum-treated sand have been tested via laboratory triaxial test apparatus (Wykeham Farrance WF10072). Xanthan gum-treated specimens were mounted directly to the bottom plate, with porous stone being placed between the soil sample and bottom plate. Another porous stone was placed on the top of the sample followed by the top cap. Finally, a rubber membrane covers the sample.

Consolidated-drained (CD) test has been performed for untreated according to ASTM D7181-11 (ASTM 2011). Vacuum pressure has been to make sand stand up itself. Saturation has been proceeded by the circulation of de-aired water and CO_2 gas until achieving a sufficient B-value (> 0.9). The back pressure of cell has been controlled as 500 kPa for saturation.

For xanthan gum-treated sand, molded specimens have been tested without saturation to obtain the strength of dried xanthan gum-treated sand under triaxial loading. The consolidation procedure has been omitted as well as saturation. As xanthan gum-treated sand is regarded to be fully dried, drainage has not been considered during deviator stress loading.

The applying isotropic cell pressure and deviator stress is controlled by Standard pressure/volume controller (GDS STDDPC), and the strain rate is measured by external LVDT (Linear Variable Differential Transformer). The confinement conditions are 50 kPa, 100 kPa, and 200 kPa. The strain rate is 0.1% min^{-1}.

EXPERIMENT RESULTS

The shear behavior of untreated sand (medium dense; $D_r = 70\%$) shows peak behavior as shown in Fig. 2(a). The peak shear strength increases gradually as the confinement pressure is increased. Thereafter, the friction angle of untreated sand is determined as 38^0 based on the Mohr-coulomb failure diagram as shown in Fig. 2(b).

Xanthan gum-treated sands show higher strengthening effect with xanthan gum content increase. For instance, the stiffness of 1.0% biopolymer-treated sand is slightly enhanced as the confining pressure is increased, as shown in Fig. 3. Moreover, xanthan gum-treated sands show higher ductility compared to untreated sand, where ductility increases with higher xanthan gum content and confining stress levels (Fig. 3a).

In addition, cohesion of xanthan gum-treated sand substantially increases as xanthan gum content increase (Fig. 4b), while friction angle does not show remarkable change at low xanthan contents but slightly increases at m_{bp}/m_s =2.0% (Fig. 4a). In details, the cohesion is increased from 18 kPa of untreated soil (it can be regarded as a negligible value) to 216.9 kPa, 252.8 kPa, and 365.2 kPa with higher xanthan gum contents (Fig. 4b).

DISCUSSION

Xanthan gum enhances inter-particle bonding characteristic due to the formation of firm biofilms residues through the dehydration of hydrogels (Chang et al. 2015). Regardless of confinement conditions, the xanthan gum-treated sand shows higher strength than untreated sand. Thus, it can be regarded that xanthan gum treatment is more effective at shallow depth conditions where the confinement level is low or negligible. Indeed, the strengthening efficiency increases with higher xanthan gum contents.

Experimental results of this study (both untreated and xanthan gum-treated sands) and results from previous studies (Ayeldeen et al. 2016; Latifi et al. 2016; Lee et al. 2017) show that biopolymer induced soil strengthening mostly attributes to the inter-particle cohesion improvement rather than affecting the physical friction characteristic of soils. Thus, the higher strengthening effect by xanthan gum treatment can be explained to be a result of the formation of thicker biopolymer films due to the higher xanthan gum content.

However, this study has a limitation where it does not consider the water content variation and water-dependent hydrogel transfer of xanthan gum (Lee et al. 2017). Despite xanthan gum treatment show promising sand strengthening at the initially mixed and dried conditions, post-saturation after drying may render awkward strength behaviors where re-hydrated xanthan gum hydrogels are expected to swell and deduce inter-particle bonds (Chang et al. 2017).Thus, the cohesion variation of xanthan gum-treated sand subjected to further re-hydration and re-dehydration needs to be investigated by future studies.

CONCLUSION

The xanthan gum induces higher strength by inter-particle bonding between soil particles with development of biopolymer film after enough drying process. The peak strength at 0.5% xanthan gum-treated condition is approximately at least 2 times higher regardless of confinement condition as shown in Fig. 2. Enhancement of peak strength is substantial compared to untreated condition regardless of confinement pressures, and the peak strength at the higher confinement condition is higher than 1.5 MPa even with 0.5% xanthan gum treatment in mass ratio. Meantime, the tri-axial shear strength of xanthan gum-treated sand is increased as higher confinement pressure is applied, which is reflected to describe the important in-situ parameter. In other words, application of xanthan gum treatment is still valid under specific amount of confining pressure. Therefore, it can be assumed that the application of hydro-gel type biopolymer is effective at the shallow depth for practical implementation.

In addition, the shear strength is enhanced according to xanthan gum content. Triaxial shear behavior of xanthan gum-treated sand shows significant increase on cohesion with xanthan gum content increase. It can be explained that the higher cohesion which is developed by biopolymer film strands between soil particles, resists against external shearing forces. In other words, the cohesion of xanthan gum-treated sand is a main factor which is related to shear behavior in case of fully dried specimens.

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