Effects of biopolymer on the consolidated-drained static triaxial test behavior of sand

Jooyoung Im[1], S. Lee[2], G.-C. Cho[1], and I. Chang[2]

[1] Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, 34141, Republic of Korea

[2] School of Engineering and Information Technology, University of New South Wales (UNSW), Canberra, ACT 2600, Australia

ABSTRACT

In recent years the sustainable and eco-friendly engineering in geotechnical engineering has been a major focus of research. Environmental concerns on conventional materials such as ordinary cement have been shown to have several harmful side effects to its mass use. The use of cement has been correlated to harmful environmental concerns such as greenhouse gas (CO_2) emissions and groundwater contamination in the field of geotechnical and environmental engineering. Although cement has been recognized as an environmentally unsustainable material, its importance for construction purposes cannot be overlooked. This is mainly due to the lack of a suitable replacement. One promising material that shows potential to alleviate the environmental stress that is present with cement use is the use of biopolymers. Biopolymers have been known to be a sustainable material that is generally environmentally friendly. It has been used in numerous fields, and its use as a binder in ground engineering may help with some of the environmental stress produced by current methodologies. For this study the triaxial behaviors of biopolymer treated sands were tested under consolidated drained conditions. The results showed that the treatment of biopolymers provides an increase in strength mainly through the increase in interparticle cohesion.

Keywords: biopolymer, sand, triaxial test, strength

1 INTRODUCTION

In recent years the trend towards sustainable and eco-friendly engineering in geotechnical engineering has been a major focus of research. This is due to environmental concerns on conventional materials such as ordinary cement. The use of cement has been correlated to harmful environmental concerns such as greenhouse gas (CO_2) emissions and groundwater contamination in the field of geotechnical and environmental engineering (Chang and Cho 2012; Chang et al. 2016). Although cement has been recognized as an environmentally unsustainable material, its importance for construction purposes cannot be overlooked. This is mainly due to the lack of a suitable replacement. However, several methods and materials have been researched that may help alleviate the dependence of geotechnical construction on cement and other similar binders.

One promising material is microbial biopolymers. Biopolymers are organic polymers that are mainly derived from organic processes. Biopolymers have been widely applied in various fields of medicine, agriculture, food, and industry. In geotechnical engineering, previous studies have also shown that the use of biopolymers in soils is capable of enhancing various properties of soils, such as increases in strength (Fig. 1), shear strength properties, and reductions in soil permeability (Chang et al. 2016; Chang et al. 2015; Chang et al. 2015).

As the effects of biopolymers in soils can cause many changes in the engineering performance of the soils (Aminpour and O'Kelly 2015; Bouazza et al. 2009; Chang et al. 2018; Chang et al. 2015), triaxial tests of biopolymer treated and untreated sands will be tested in this study. In this study, the effects of xanthan gum treated sands are tested under the consolidated drained triaxial tests, and its effects on the strengthening parameter in addition to its changes in pore pressure through the loading process are observed.

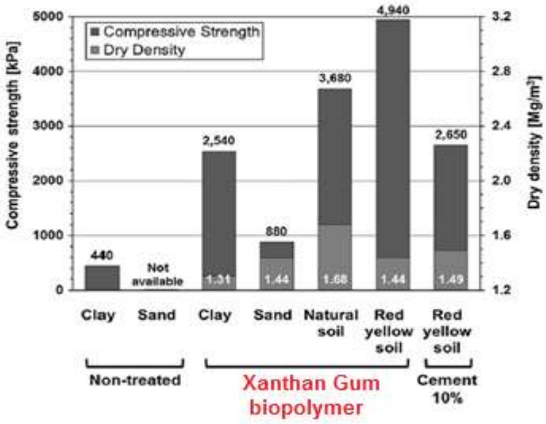

Fig. 1. Strengthening Effects of Biopolymer treated Soils (Chang et al. 2015).

2 MATERIALS AND METHOD

2.1 Materials

Sand

The soil used in this study is Sydney sand. Basic properties of Sydney sand are summarized in Table 1.

Table 1. Properties of Sydney sand.

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

Xanthan gum

The biopolymer used for this study is Xanthan gum. Xanthan gum is a polysaccharide that is produced from the bacterium Xanthomonas campestris (Candia and Deckwer 2002). It consists of two glucose units, two mannose units, and one glucuronic acid unit (Becker et al. 1998). Xanthan gum has been used in many fields such as pharmaceuticals, agriculture, medicine, and cosmetics (Babbar and Jain 2006; Becker et al. 1998). In geotechnical engineering aspects, xanthan gum is reported to affect the soil consistency (Chang et al. 2018) and direct shear strength of soils (Lee et al. 2017).

2.2 Method

Sample Preparation

Research grade xanthan gum (Sigma Aldrich; CAS: 11138-66-2) was dissolved into deionized water at a specified water content (w = 20% to soil mass). The biopolymer solutions were set at 0.5% and 1.0% biopolymer content to the soil mass (m_b/m_s). Once the xanthan gum was fully gelatinized by thoroughly mixing the biopolymer into deionized water for 30 min, the solution was directly mixed into the soil and molded into a cylindrical shape (50 mm-diameter, 100 mm-height). Once molded, samples were either directly tested (initial state) or dried in an oven at 50°C for 28 days (dry state). Initial and dry states were compared to investigate the xanthan gum hydrogel dehydration effect on the shear behavior of xanthan gum-treated sands.

Experimental Procedure

For triaxial test consolidated drained (CD) test with the implementation of wet mounting method has been conducted according to the ASTM D7181 (ASTM 2011). The specimens were repeatedly flushed with CO_2 and saturated with de-aired water for 3 time-cycles under a back-pressure of 500 kPa applied until the B value of 0.9 has been achieved. After saturation, consolidation was commenced, and the specimens sheared. The schematic diagram of the triaxial test is shown below in Fig. 2. Biopolymer-treated soil samples were compared with untreated condition under the same testing condition.

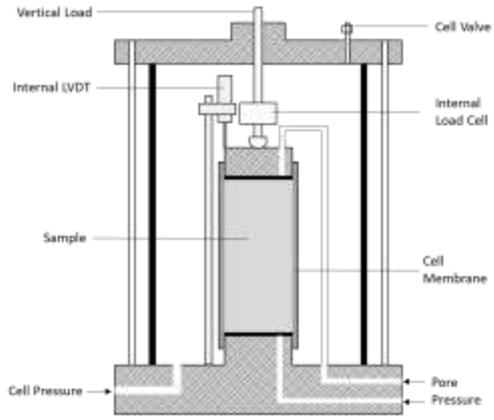

Fig. 2. Schematic Diagram of Triaxial Tests

3 TEST RESULTS

Test results are shown below in Fig. 3.

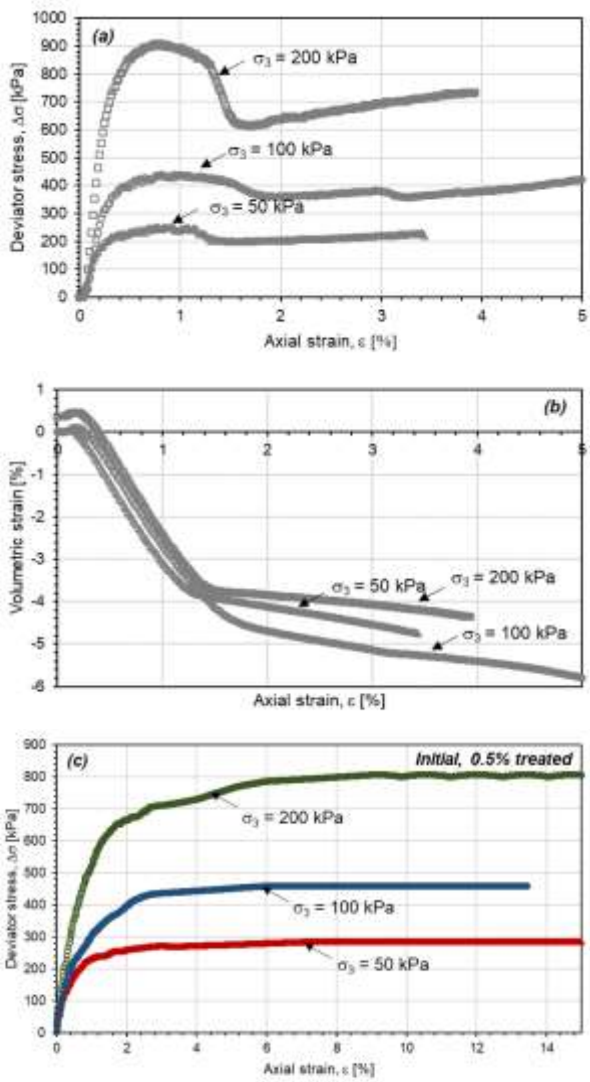

Figure 3. Triaxial shear behavior – (a), (b): stress-strain behavior and volumetric strain-axial strain diagram of untreated sand by CD test; (c): Stress-strain behavior of gel-type biopolymer treated sand at 0.5% biopolymer content in initial state.

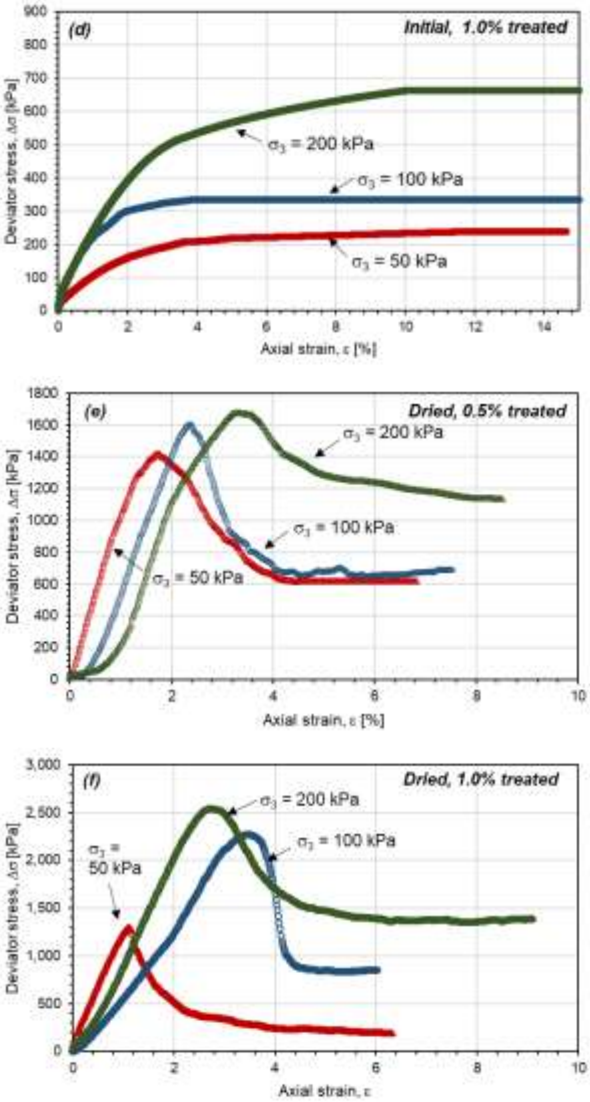

Figure 3. Continued – (d): Stress-strain behavior of gel-type biopolymer treated sand at 1.0% biopolymer content in initial state; (e) and (f): Stress-strain relationship of gel-type biopolymer treated sand at 0.5% and 1.0% biopolymer content in dried state.

Results show that the existence of xanthan gum does not have significant effect on the shear strength at initial (wet) conditions (Figs. 3a, c & d). Meanwhile, xanthan gum-treated soils at dried state show a remarkable improvement in the shear strength of the soils (Fig. 3 e & f) in comparison to untreated and initial (wet) xanthan gum-treated conditions. However, with the case of the initial treated soils, the use of xanthan gum showed diminishing strengths in comparison with untreated sands.

In Fig. 4 we observed the pore pressure changes with loading for the biopolymer treated initial conditions. As seen at the 0.5% biopolymer treated soils, there is a reduction in the pore water pressure with the failure of the samples due to the volumetric expansion of the samples. However, in the 1.0% conditions we see the opposite trends in which there is a buildup in the pore water pressure with loading. The difference in behavior is due to the low hydraulic conductivity of the biopolymer treated soils at higher concentrations. Due to the reduced permeability from hydrogel soil clogging effects (Chang et al. 2016), the loading behavior resembles the undrained tests for the 1.0% biopolymer treated soils.

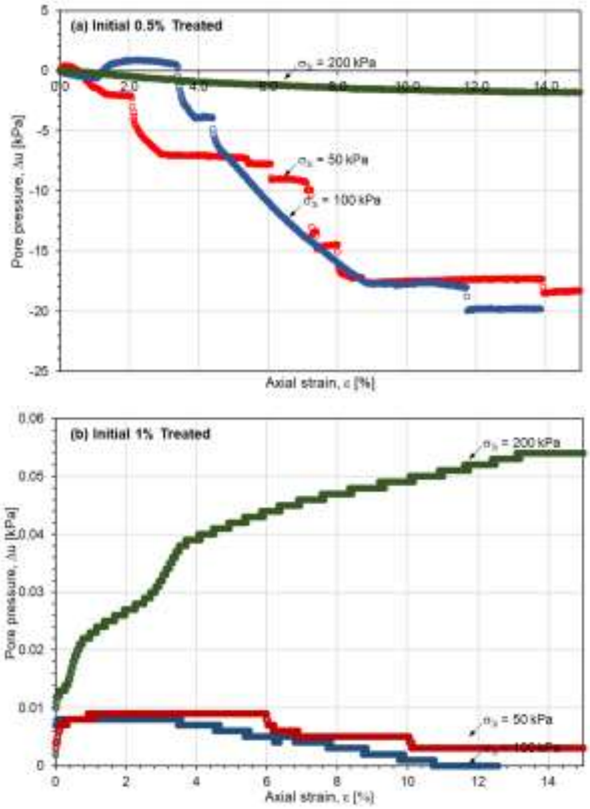

Figure 4. Pore water pressure changes with loading for (a) 0.5% treated initial condition (b) 1.0% treated initial condition

In addition, when we observe the shear strength parameters of the biopolymers (Table 2) it can be seen that the use of xanthan gum reduces the friction angle of the soils. However, xanthan gum treated soils are always expected to have a cohesion increase, where the cohesion enhancement maximizes through xanthan gum hydrogel dehydration. Thus, it can be concluded that that xanthan gum treatment improves the soil strength mainly through inter-particle cohesion increase.

Table 2. Shear parameters of untreated and Xanthan gum treated sands.

Shear strength properties	Untreated	Xanthan gum-treated			
		Initial		Dry	
		0.5%	1.0%	0.5%	1.0%
Friction angle, ϕ [°]	40.3	38.0	27.4	35.3	27.6
Cohesion, c [kPa]	16.2	29.2	42.6	403.6	516.3
Stiffness [MPa] (50 kPa confinement)	88.9	28.5	6.2	87.5	128.7

4 CONCLUSIONS

In conclusion, the use of Xanthan gum biopolymer treatment in triaxial tests has shown that the biopolymer is capable of increasing the dry stiffness of the soils, while providing cohesion to the sands, with a slight decrease in friction angle. Additionally, in the initial state, the use of Xanthan gum has shown an overall decrease in strength at higher confinements, and at higher biopolymer concentrations the loading effects are similar to undrained tests due to its low permeability. However, analysis has shown an increase in cohesion indicating that its use at shallow depth show benefits.

During testing it was also noted that the use of biopolymers greatly inhibited the flow of water through the samples. This created a bio-clogging effect that severely limited the effect of consolidation on the soil samples. As such further tests on this will need to be taken.

ACKNOWLEDGEMENTS

This research was supported by a grant (18AWMP-B114119-03) from the Water Management Research Program funded by the Ministry of Land, Infrastructure, and Transport (MOLIT) of the Korean Government; a National Research Foundation of Korea (NRF) grant funded by the Korean Government (MSIP) (No. 2017R1A2B4008635); and a grant (18SCIP-B105148-04) from the Construction Technology Research Program funded by the MOLIT of the Korean Government.

REFERENCES

Aminpour, M., and O'Kelly, B. C. "Applications of biopolymers in dam construction and operation activities." *Proc., The Second International Dam World Conference (DW2015)*, 937-946.

ASTM (2011). "D7181-11: Method for Consolidated Drained Triaxial Compression Test for Soils." ASTM International, West Conshohocken, PA, 11.

Babbar, S. B., and Jain, R. (2006). "Xanthan gum: an economical partial substitute for agar in microbial culture media." *Current microbiology*, 52(4), 287-292.

Becker, A., Katzen, F., Pühler, A., and Ielpi, L. (1998). "Xanthan gum biosynthesis and application: a biochemical/genetic perspective." *Applied Microbiology and Biotechnology*, 50(2), 145-152.

Bouazza, A., Gates, W., and Ranjith, P. (2009). "Hydraulic conductivity of biopolymer-treated silty sand." *Géotechnique*, 59(1), 71-72.

Candia, J. L. F., and Deckwer, W. D. (2002). "Xanthan Gum." *Encyclopedia of Bioprocess Technology*, John Wiley & Sons, Inc.

Chang, I., and Cho, G.-C. (2012). "Strengthening of Korean residual soil with β-1,3/1,6-glucan biopolymer." *Constr. Build. Mater.*, 30(0), 30-35.

Chang, I., Im, J., and Cho, G.-C. (2016). "Geotechnical engineering behaviors of gellan gum biopolymer treated sand." *Can. Geotech. J.*, 53(10), 1658-1670.

Chang, I., Im, J., and Cho, G. C. (2016). "Introduction of microbial biopolymers in soil treatment for future environmentally-friendly and sustainable geotechnical engineering." *Sustainability*, 8(3), 251.

Chang, I., Im, J., Prasidhi, A. K., and Cho, G.-C. (2015). "Effects of Xanthan gum biopolymer on soil strengthening." *Constr. Build. Mater.*, 74(0), 65-72.

Chang, I., Kwon, Y.-M., Im, J., and Cho, G.-C. (2018). "Soil consistency and inter-particle characteristics of xanthan gum biopolymer containing soils with pore-fluid variation." *Can. Geotech. J.*

Chang, I., Prasidhi, A. K., Im, J., Shin, H.-D., and Cho, G.-C. (2015). "Soil treatment using microbial biopolymers for anti-desertification purposes." *Geoderma*, 253–254(0), 39-47.

Lee, S., Chang, I., Chung, M.-K., Kim, Y., and Kee, J. (2017). "Geotechnical shear behavior of xanthan gum biopolymer treated sand from direct shear testing." *Geomech. Eng.*, 12(5), 831-847.