The effect of soil composition and xanthan gum biopolymer on the undrained shear strength

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ABSTRACT

Previous geotechnical engineering materials raise environmental concerns such as global warming (i.e., high CO_2 emission), groundwater contamination, and aeolian dust inducing air pollution. Biopolymer application for geotechnical engineering purposes has been introduced as an alternative to reduce the usage of conventional geotechnical engineering soil binders. Biopolymer has a promising function of increasing soil strength, reducing erosion and hydraulic conductivity. However, there is a lack of in-depth research into the interaction between biopolymers and fine-grained soil particles. This study focuses on understanding the effect of xanthan gum biopolymer on the undrained shear strength of soils with various fine-grained soil content through a series of fall cone tests. Additionally, the correlation between undrained shear strength and water content is conducted based on the previously suggested equation. Soil with higher clay content shows higher undrained shear strength at same water content, and the presence of xanthan gum biopolymer in soils improves the undrained shear strength. The optimum undrained shear strength was observed with 0.5% of xanthan gum to clay ratio in mass, regardless of soil composition, which implies that clay proportions rather than coarse-grained soils mainly govern the effect of xanthan gum treatment.

Keywords: biopolymer; undrained shear strength; xanthan gum; soil composition; fall cone test

1 INTRODUCTION

Shear strength is one of the most critical factors for the stability of geo-structures (Chang and Cho 2018). For fine-grained soils with low permeability, undrained shear strength prevails for short-term (i.e., undrained condition) stability (Sridharan and Prakash 1999). In geotechnical engineering practice, cement-based materials have been commonly used for soil stabilization (Chapman 2004). However, cement used for construction purpose causes environmental concerns such as CO_2 emission (Rehan and Nehdi 2005), groundwater contamination (Burton and Pitt 2002), and soil basification (Taylor 1997). Thus, previous research has suggested microbial induced biopolymer as an environment-friendly soil stabilization material. Biopolymers show its potentials to enhance inter-particle bonding (Chang et al. 2015) and accompanying shear strength of soils (Chang and Cho 2018), while also indicates a significant decrease on hydraulic conductivity of soils via pore-clogging (Chang et al. 2016; Chang et al. 2017). However, previous studies mainly focused on the biopolymer application for coarse-grained soils, and the detailed studies on the biopolymer application on the fine-grained soils are required.

This study uses xanthan gum biopolymer to enhance the undrained shear strength of soils with various soil compositions from sand to clays. The undrained shear strength is measured by a series of fall cone test with varying water contents. Experiments display a variation of undrained shear strengths with xanthan gum content (0-2% of soil mass) and soil composition (100% clay; 50% clay: 50% sand; 20% clay: 80% sand). Undrained shear strength parameters were assessed to verify the effect of soil composition, xanthan gum content on soil shear strength.

2 MATERIALS AND METHODS

2.1 Soils: Kaolinite and Jumunjin sand

In this study, kaolinite clay and Jumunjin sand were mixed with different composition ratios (clay: sand) as 10:0 (pure clay); 8:2; and 5:5 (clayey sand). Jumunjin sand is classified as SP (poorly graded sand), which is mainly composed of quartz (SiO_2) and regarded to be electrically neutral. The basic properties of Jumunjin sand are as the following: D_{50} = 0.42 mm, C_u = 1.54, and C_c = 0.96.

Kaolinite is one of the most common clay minerals which has a stable 1:1-layer structures of gibbsite and silica sheets. Kaolinite minerals adsorb water molecules by hydrogen bonding due to electrical charges on the surface of kaolinite. This study uses kaolinite (D_{50} = 3 μm and *SSA* = 22 m^2/g) from Belitung Island, Indonesia.

2.2 Biopolymer: Xanthan gum (XG)

Xanthan gum (XG) is a negatively charged polysaccharide produced by the metabolism of *Xanthomonas campestris* bacteria. When dissolved in water, XG forms a viscous hydrogel, and thus, XG has been used as a stabilization agent in aqueous formation and thickener in food, drug industries. XG has also been introduced as a soil stabilization agent by increasing strength (Cho and Chang 2018) or reducing hydraulic conductivity (Martin et al. 1996) of soils.

Research grade XG (Sigma-Aldrich Co, CAS: 11138-66-2) is thoroughly mixed with oven-dried soils to the biopolymer to soil ratio in mass (m_b/m_s) between 0-2 %.

2.2 Shear strength (S_u^{FC}): Fall cone test

This study adopts the fall cone test for measuring the S_u^{FC} of soils. The fall cone penetration depth and S_u^{FC} has a relationship as Eq. (1) (Hansbo 1957).

$$s_u^{FC} = K\frac{mg}{d^2} \tag{1}$$

where *K* is the cone factor, *m* is the mass of cone, *g* is gravimetric acceleration, and *d* is penetration depth.

This study uses a cone with an 80 g mass and 30° tip angle, and K = 0.867 which corresponds with S_u^{FC} of 1.7 kPa at liquid limit state (Wroth and Wood 1978). S_u^{FC} with more than three different water content is obtained, and the reliability of S_u^{FC} is assured by repeating fall cone tests at least three times for each condition.

2.3 Shear strength parameters: *a* and *b*

S_u^{FC} and water content are correlated exponentially with shear parameters *a* and *b* (Koumoto and Houlsby 2001) as Eq. (2).

$$w = a \cdot s_u^{-b} \tag{2}$$

where *w* is the water content, shear parameter *a* is water content at the S_u^{FC} of 1 kPa, and *b* is the variation of S_u^{FC} with water content.

Geotechnical parameters such as specific surface area (*SSA*), mineral structure, soil composition, and pore fluid chemistry are regarded to affect shear parameters *a* and *b* (Dolinar and Trauner 2005; Dolinar and Trauner 2007; Trauner et al. 2005).

3 RESULTS AND ANALYSIS

3.1 S_u^{FC} -water content relation

Fig. 1 shows the variation of S_u^{FC} with water content. The S_u^{FC} of XG 0% soils (empty rectangles) in Fig. 1 (a), (b) and (c) indicates that soils with higher clay content have higher S_u^{FC} at the same water content.

Higher S_u^{FC} with clay treatment is mainly due to the water adsorption on the clay surface because the amount of free pore water determines the S_u^{FC} (Trauner et al. 2005). For the soil composition, XG treatment shows an increase in the S_u^{FC} with same water content while it does not increase linearly with XG content. Increase in S_u^{FC} mainly occurs due to the charge characteristics of XG molecules. XG adsorbs water molecules and decreases the amount of free pore water. Additionally, XG transforms pore fluids into viscous hydrogel which causes an increase in the viscosity of pore fluids. Therefore, XG mainly increases the S_u^{FC} of soils.

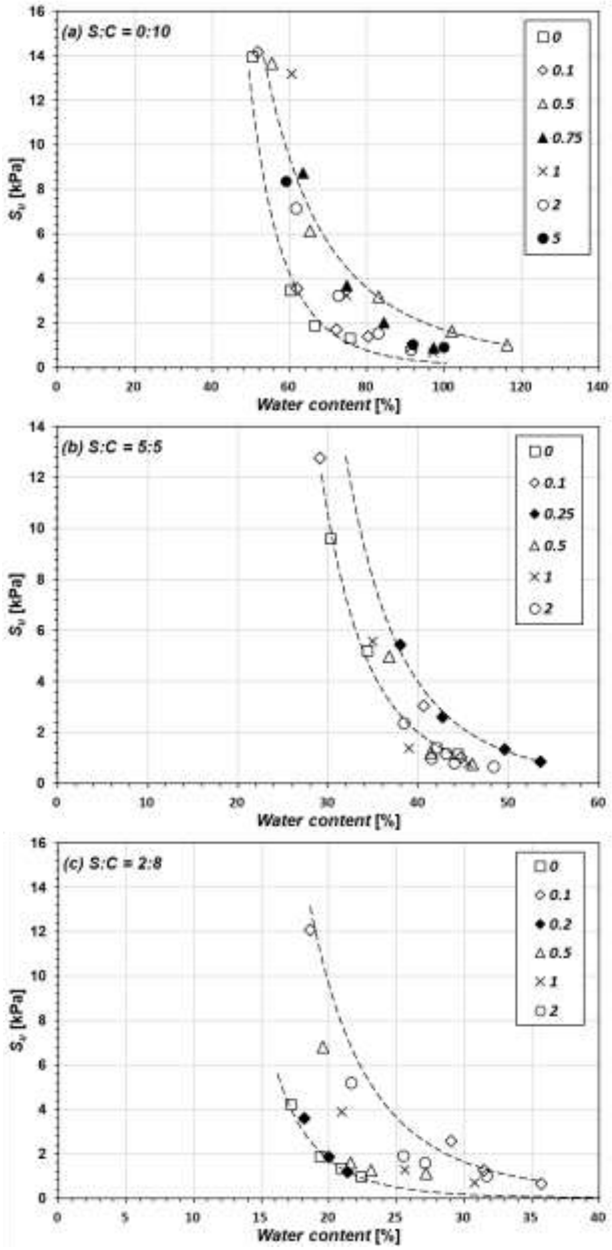

Fig. 1. S_u^{FC} variation with water content: (a) Pure clay, (b) 50% clay, and (c) 20% clay.

The maximum S_u^{FC} is observed with m_b/m_s = 0.5%, 0.25%, and 0.1% of for 100% clay, 50% clay, and 20% clay, respectively. In terms of XG to clay ratio in mass (m_b/m_c), all kaolinite-sand soils show a peak S_u^{FC} at m_b/m_c = 0.5 %. Previous research also mentioned that m_b/m_c governs the geotechnical parameters of soils

(Chang and Cho 2018; Chang et al. 2018). However, S_u^{FC} tends to decrease with the m_b/m_c of larger than 0.5%. It is mainly due to the aggregation of clay particles via particle bonding (Chang et al. 2018; Nugent et al. 2009). Reduction in surface area by particle aggregation reduces the amount of free pore water.

3.2 Shear parameters *a* and *b*

Fig. 2 indicates the effect of m_b/m_c on the shear parameters *a* and *b*. The variation of shear parameter *a* with soil composition indicates that water adsorption by clay minerals increases the S_u^{FC} of soils, while the parameter *b* shows no variation for untreated soils. It indicates that clay content increases the S_u^{FC} at the same water content, while the variation of S_u^{FC} with water content is not controlled by clay content.

With XG treatment, both *a* and *b* parameters peaks at 0.5% of mb/mc regardless of soil composition because the XG mainly interacts with clay minerals and increases the specific surface area of XG-clay media. With m_b/m_c of 0.5 to 1.0 %, XG decreases both shear parameters *a* and *b* which imply the particle aggregation of clay particles induced XG bonds.

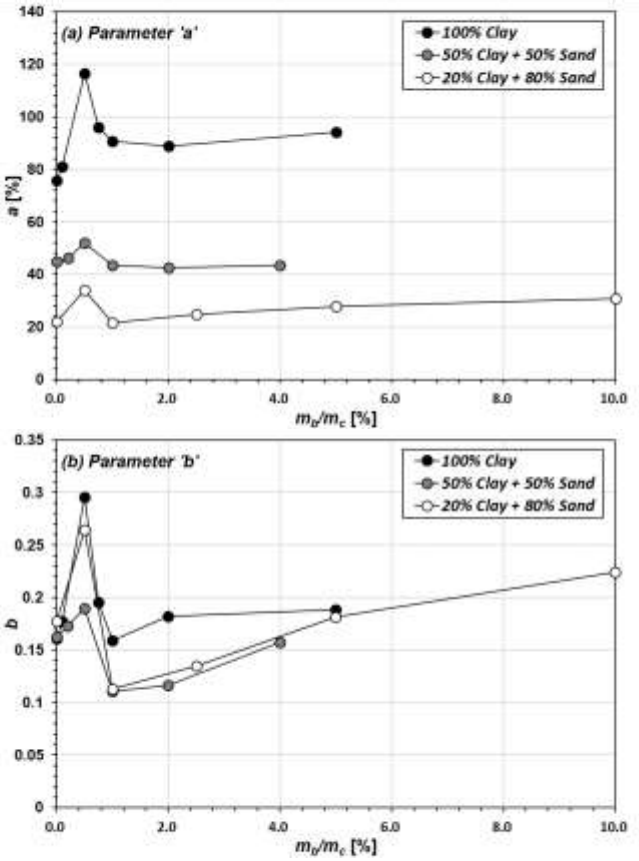

Fig. 2. The effect of XG to clay ratio on the shear strength parameters.

Particle aggregation induced by XG ends up with over 1.0% of mb/mc. Therefore, XG increases both shear parameters while it does not recover the maximum parameters up to 10% of m_b/m_c.

4 CONCLUSION

The undrained shear strength of xanthan gum treated soils with three different soil compositions (100% clay, 50% clay, and 20% clay-containing soils) were analyzed using laboratory fall cone tests. The experimental results show that both fine-grained soils and xanthan gum biopolymer tend to improve the undrained shear strength of soils by adsorbing water molecules.

Furthermore, parametric studies show that 0.5% of xanthan gum to clay ratio in mass, regardless of soil composition, is the optimum xanthan gum content to achieve the highest undrained shear strength. Over 0.5% of xanthan gum to clay ratio in mass, undrained shear strength parameters (*a* and *b*) decrease with xanthan gum due to xanthan gum induced particle aggregation effect. Findings indicate that clay content governs xanthan gum behavior, which is in accordant to previous research.

The result of this study can be a basis to suggest the standards for xanthan gum application in soils containing fine-grained soils.

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