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# Introduction of biopolymer-based materials for ground hydraulic conductivity control

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ABSTRACT: The use of a hydraulic barrier to prevent or constrain the water flow or/and residual contaminant-containing water from leaking, flowing into underground constructions such as tunnels has been addressed in the past decades. There are different types of barrier materials used to improve hydraulic properties such as soil – bentonite, cement-bentonite, soil admixes using bentonite, cement, and asphalt, chemical and other additives mixed with the natural soil. In fact, the hydraulic barrier materials used for tunnels need to work well under the earth pressure and hydrostatic water pressure acting on the tunnel lining. In this study, a linear polysaccharide gellan gum, which has been investigated in the fields of pharmaceutical technology, biomedical applications, and food products, will be used to improve the hydraulic behavior of sand. The advantage of gellan gum biopolymer is its capable of forming hydrocolloid gels when mixed with heated water and limiting water flow through the gel performance in soil hydraulic conductivity control at various depth and pore pressure conditions. A pressurized hydraulic system allows performing various pore water pressure and confinement condition to observe the pore clogging behavior of gellan gum biopolymer treated sands. Furthermore, soil hydraulic conductivity variations due to changes in confinement pressure and pore water pressure will be observed.

## 1 INTRODUCTION

Recently, the use and application of biopolymer-soil treatment in geotechnical engineering practices is actively investigated and attempted by numbers of research. A considerable amount of literature has been impressed the promising future of the use of biopolymers in practical geotechnical engineering. Biopolymer can enhance the inter-particle cohesion of soil (Lee et al., 2017, Im et al., 2017, Chang and Cho, 2018), therefore, it shows a good performance in soil strengthening (Chang and Cho, 2012, Chang et al., 2016b, Chang et al., 2015b, Khatami and O'Kelly, 2012, Chang et al., 2015a), in dust controlling (Chen et al., 2015, Miękoś et al., 2017, Larson et al., 2010), and anti-desertification (Chang et al., 2015c). Another advantage of the biopolymer is its water holding capacity, therefore, it can lend positive performance in hydraulic reduction (Chang et al., 2016b, Bouazza et al., 2009).

The use of a hydraulic barrier to obstruct the water flow or/and residual contaminant-containing water leaking and flowing into underground constructions such as tunnels has become common method in the past decades. There are different types of hydraulic barrier materials used to improve the hydraulic properties of the ground, such as soil-bentonite, cement-bentonite, soil admixes using bentonite, cement, and asphalt, chemical and other additives mixed with the natural soil (Karol, 2003, Pusch, 2015, Warner, 2004). In fact, the hydraulic barrier materials used for tunnels need to work well under the earth pressure and hydrostatic water pressure acting on the tunnel lining. In this study, the applicability of a linear polysaccharide (gellan gum) as a new admixture to soil for ground hydraulic conductivity control is investigated. The advantage of gellan gum biopolymer is its capable of forming hydrocolloid gels when mixed with heated water and limiting water flow through the gel performance in soil hydraulic conductivity control at various depth and pore pressure conditions.

As the hydraulic barrier is constructed at a certain depth with an appearance of groundwater, hydraulic barrier materials will be subjected to quick and high effective stress and water pressure. A pressurized hydraulic conductivity device, which allows performing various pore water pressure and confinement condition, has been suggested (Chang et al., 2016b). For the advantage, the device was used to perform hydraulic tests on sand and sand/clay mixture to see the effectiveness of gellan gum on hydraulic reduction of different type of soils.

## 2 MATERIALS AND EXPERIMENTAL PROCESS

### 2.1 *Biopolymer and soil*

#### 2.1.1 *Soil types*

Jumunjin sand is a standard sand in Korea, which is classified as poorly graded sand (*SP*) according to USCS classification. It has an average particle size of 0.46 mm, specific gravity ($G_s$) of 2.65, and the coefficient of uniformity ($C_u$), and the coefficient of gradation ($C_c$) are found to be 1.39 and 0.76 respectively (Chang et al., 2018, Chang et al., 2017, Chang and Cho, 2018).

A commercial kaolinite – Bintang kaolin, which is classified as *CH* according to the USCS classification is used as an additive to enhance the rheology of gellan gum. It has the specific gravity of 2.7 and average particle size of 44 $\mu m$. The clay powder was mixed with jumunjin sand with a ratio of clay to sand at 1:9 to obtain sand-clay mixture.

#### 2.1.2 *Gellan gum*

Gellan gum is a linear polysaccharide produced by the bacterium Pseudomonas elodea, which has been investigated in the fields of pharmaceutical technology, biomedical applications (Osmałek et al., 2014), food industry (Morris et al., 2012, Saha and Bhattacharya, 2010, Imeson, 1992). Moreover, gellan gum applicability to geotechnical engineering such as soil strengthening (Chang and Cho, 2018, Chang et al., 2017, Chang et al., 2015b), hydraulic conductivity control (Chang et al., 2016a). In this study, low acyl gellan gum biopolymer supplied by Sigma Aldrich (CAS No.71010-52-1) has been used.

### 2.2 *Sample preparation and experiment procedure*

#### 2.2.1 *Sample preparation*

Biopolymer hydrogels were mixed with soils at target biopolymer to soil contents in mass as 0.5% and 1.0%. To allow thorough mixing the initial water content has been set at 33%. Gellan gum powder was first dissolved and hydrated into deionized water heated at 100°C to obtain uniform gellan gum solution. Thereafter, dry soil and heated gellan gum solution were uniformly mixed.

#### 2.2.2 *Experimental procedure*

The hydraulic conductivity of soil was determined by using a pressurized hydraulic conductivity test apparatus (Figure 1). The gellan gum hydrogel – soil mixtures were set into a cylindrical cell which is 9.3 cm in height and 8.0 cm in diameter. At the top and

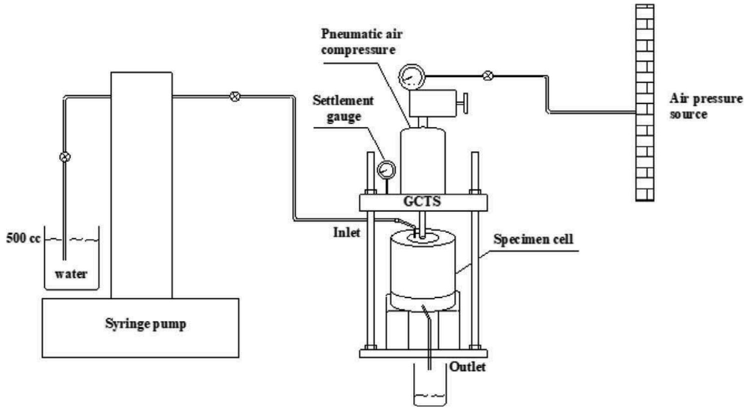


Figure 1. Schematic diagram of hydraulic conductivity setup.

bottom of the specimen, filter papers were placed so that water can evenly distribute within specimen during the experimental process. After the specimen was fully set up and cooled down, confining pressure was then applied to the soil under drained condition using a pneumatic air compressor so that the effective stress acting on the soil should be 100, 200 and 400 kPa. The consolidation process lasted for 24 hours at where vertical strain of soil reached constant. Wet curing was carried out for de-airing and saturation purpose under undrained condition. A constant water pressure of 70 kPa into specimen using a high-pressure precision syringe pump. As the flow rate of water reached zero, the authors assumed that the specimen was fully saturated, and the permeability test was conducted. After drained equilibrium was completed, the permeability of soil was then observed at varying water pressure, which started by 70 kPa. At each confining stress (i.e effective stress), the constant water pressure was increased until the water pressure was significantly higher than effective stress.

The saturated permeability is calculated based on Darcy's law:

$$k = \frac{V \cdot L}{A \cdot h \cdot t} \tag{1}$$

where V is the collected volume of water, L is the height of soil specimen, A is the area of soil specimen, h is the head difference, and t is the time required to the V volume

## 3 RESULTS AND ANALYSIS

### 3.1 *Effect of gellan gum on hydraulic reduction for soils*

The hydraulic conductivities of gellan gum-treated sand and sand/clay mixture are shown in Figure 2 and Figure 3. For untreated soils, average permeability of pure sand and sand/clay mixture are 7.15 x 10-7 m/s and 6.18 x 10-7 m/s, respectively. The presence of kaolinite did not improve the hydraulic reduction of sand. It is due to the low water adsorb-ability of kaolinite particles, which is classified kaolinite as a non-swelling clay mineral (Osacky et al., 2015). Furthermore, water pressure was high enough to even flush clay particle out of the soils.

As the soils were treated by gellan gum, hydraulic conductivity of the soils decreased significantly by at least 10 times. The hydraulic reduction of soils was due to the water absorption ability of gellan gum which shows different mechanism regarding soil types. For pure sand, the gellan gum film coating sand surface (Chang et al., 2016a) adsorbed, held water, which controlled the flow rate of water passing through the sand specimen. For sand/clay mixture,

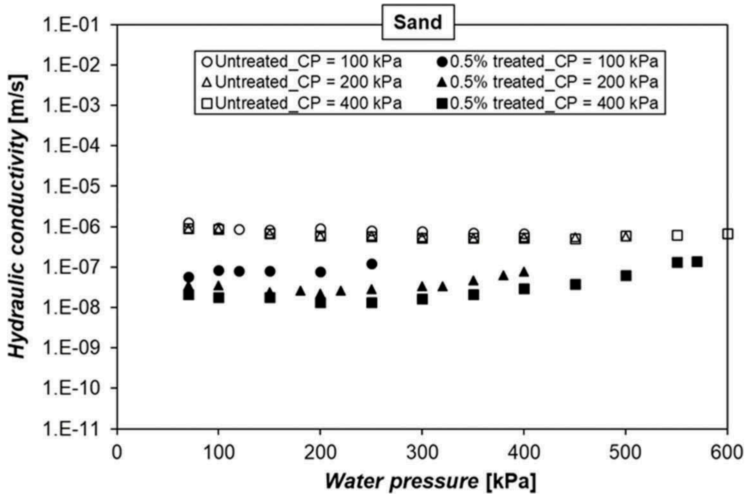


Figure 2. Hydraulic conductivity of gellan-treated sand.

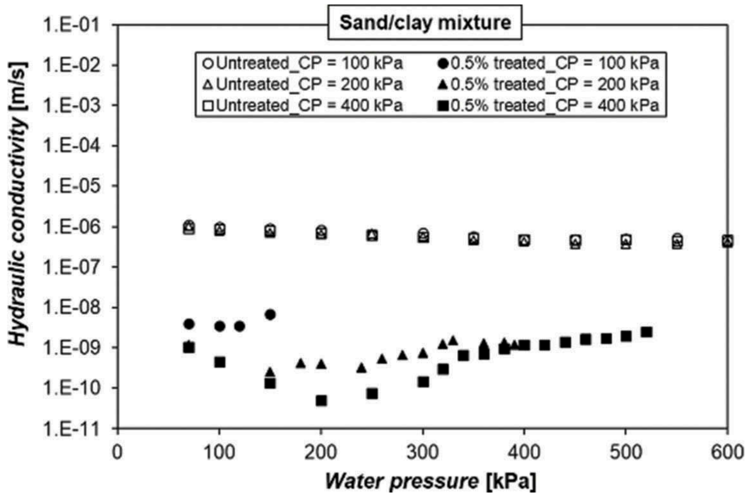


Figure 3. Hydraulic conductivity of gellan-treated sand/clay mixture.

the gellan – kaolinite matrix forming via hydrogen bonding between gellan gum biopolymer and kaolinite (Chang and Cho, 2018) performed a different contact with water molecules. The inter-particle interaction via hydrogen bonding with clay particles of gellan gum could reduce the loss of kaolinite during permeability test (Figure 4). Gellan- kaolinite matrix obstructed water flow via water adsorption of gellan gum and kaolinite, reduced flow speed.

The confinement pressure does not show any effect on the hydraulic conductivity of untreated soils, however, a slight decrease in hydraulic conductivity with confinement pressure can be seen in the case of treated soils (Figure 2 and 3). The confinement pressure arranged soil particles and reduced soil pores during the consolidation process. In other words, a slight difference in dry density (Figure 5) led to the difference in hydraulic reduction.

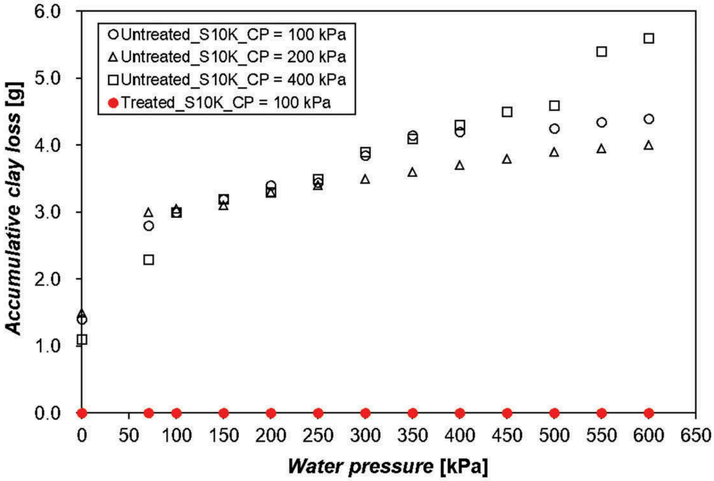


Figure 4. Effect of gellan gum on kaolinite controlling.

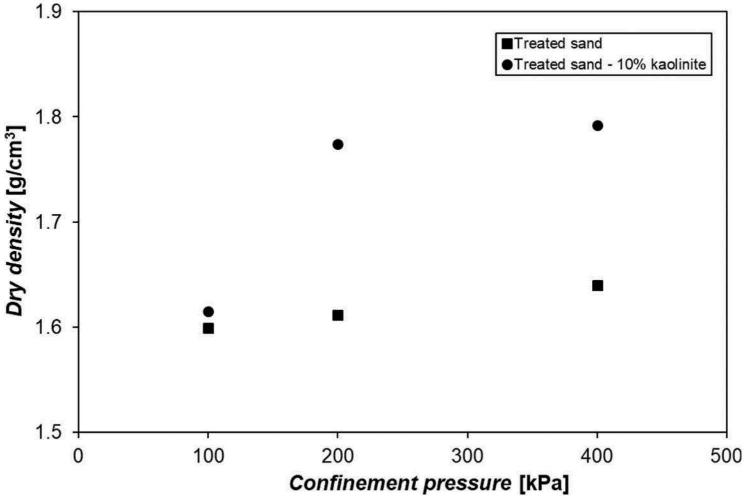


Figure 5. Dry density of soil before hydraulic test.

### 3.2 *Role of clay in hydraulic reduction effectiveness of gellan gum*

Figures 6 and 7 show the hydraulic conductivity of sand and sand/clay mixture as they were treated at the same condition of gellan gum concentration and confinement pressure. When the soils were treated with 0.5% gellan gum, sand/clay soil showed lower conductivity compared to sand. However, 1% gellan gum performed a slight difference in the conductivity of the soils. It is believed that the ratio of gellan gum and kaolinite exhibited different performance in the hydraulic conductivity reduction. At 0.5% gellan gum concentration, a number of kaolinite and gellan gum produced a strong ion bonding, which is along with water adsorption of gellan gum and kaolinite particles triggered higher reduction of the flow rate within the soil. The hydraulic conductivity of sand treated 0.5% gellan reduced by 100 times, which could drop by 1000 times with the presence of kaolinite. However, when gellan gum concentration of 1.0% was used, the presence of kaolinite showed inconsiderable effect on the water adsorption of gellan gum, and gellan gum seemed to play a dominant role in the hydraulic reduction of soil.

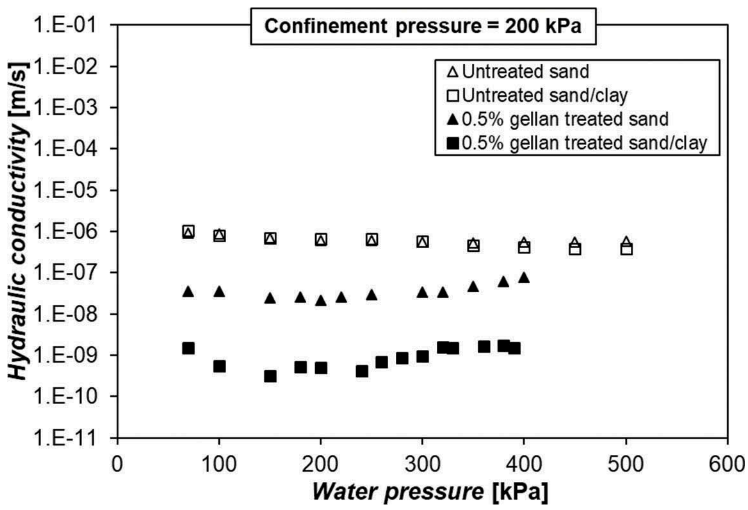


Figure 6. Role of clay in hydraulic reduction effectiveness of 0.5% gellan gum.

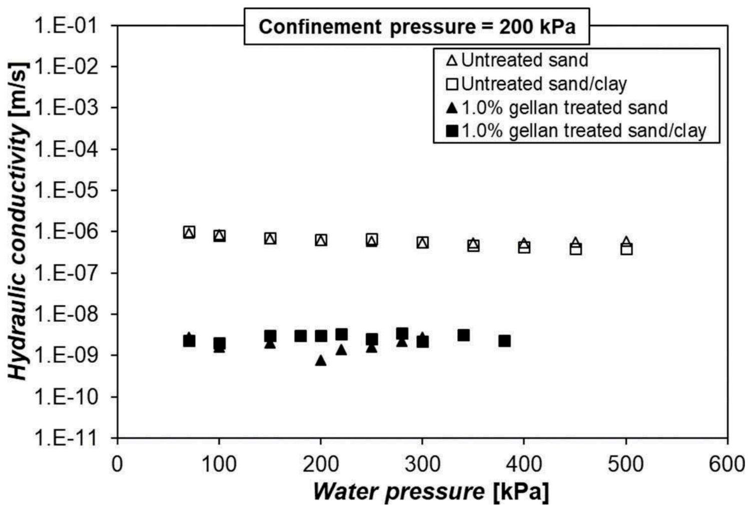


Figure 7. Role of clay in hydraulic reduction effectiveness of 1.0% gellan gum.

## 4 CONCLUSION

In conclusion a decrease in the permeability was observed with the addition of gellan gum into the soil regardless of the type of soil used. However, the presence of kaolinite can improve the effectiveness of gellan gum on hydraulic reduction, which depends largely on the number of ion bondings within the gellan-kaolinite matrix. The finding from this study can be suggested as a new hydraulic materials not only for the tunnels but underground constructions in general. For further study, higher gellan concentration should be tested to observe a general trend of hydraulic conductivity of gellan gum treated soils as gellan gum concentration increases.

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