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IMPROVING THE STABILITY OF BENTONITE SLURRY USING GELLAN GUM BIOPOLYMER

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Abstract. The distinctive properties of bentonite, including hydration, swelling, water absorption, ion adsorption, high viscosity, and thixotropy make it a valuable material for many applications in geotechnical engineering such as hydraulic barriers, drilling slurry, and landfill liners. Many additives such as cement, hay fiber, and polymer have been used to enhance the engineering performance of bentonite slurry, which are proved in respected research. This study introduces gellan gum as a friendly environmental additive that improves bentonite slurry stability when bentonite is used for soil stabilization during excavation in emergency response. The bentonite was treated with different gellan gum concentration as 0% (untreated); 2%; 3%; 4%, 5%, 6% and 7% to the mass of distilled water. A series of unconfined compression tests was conducted on gellan gum – bentonite mixture considering initial and thermal curing conditions. The test results show the soil strengthening effect of gellan gum on bentonite slurry in initial and thermal curing conditions via direct interaction between gellan gum monomer and bentonite particle.

Keywords: gellan gum, bentonite, unconfined compressive strength, thermal curing

1 Introduction

Vertical barriers have been constructed in various applications across many countries [1]. And, bentonite slurry has been used as a major material to support trenches in permeable soil, which can control the groundwater flow and contaminant transport because of its low hydraulic conductivity to water. However, prolonged exposure of bentonite to contaminated liquid causes increases in hydraulic conductivity of bentonite [2]. It has also been long recognized that swelling and shrinkage of expansive clays like bentonite caused by moisture variation may result in considerable damage to the overlying structure. Furthermore, bentonite slurry triggers severe effects on the environment because the waste discharged from its uses. Being a contaminant, bentonite is also difficult to be disposed of [3].

Additives such as lime, cement, fly-ash, and gypsum are frequently utilized to enhance the engineering performance of bentonite [4]. However, processing the materials release by-product like CO2 could be harmful to the living environment. With high consideration in environmental protection, hay fiber [5] and polymer [6] have received attention from

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geotechnical engineers for improving bentonite properties. Many studies are focused on enhancing bentonite slurry in order to meet the crucial demands of a hydraulic barrier, such as pumpability [6], permeability [6-8], adsorption effect [9, 10], and chemical resistance [11]. Furthermore, slurry wall stability is also considered a significant concern during excavation [12].

This study investigates gellan gum as a friendly environmental material for improving the stability of bentonite slurry barriers. Gellan gum biopolymer, which is found to enhance water absorption and soil strengthening via reducing porosity and improving inter-cohesion of the soil, was suggested to be a promising modifier for bentonite slurry. This study is framed by investigating the strength of the modified bentonite. In order to test the stability of the modified bentonite, a series of laboratory unconfined compression experiments was conducted on gellan gum-treated bentonite with different gellan gum concentrations under conditions with and without heating curing process. The result of the tests demonstrates an increase in shear strength of bentonite slurry with gellan gum concentration and temperature.

2 Experimental aspects

2.1 Soil and biopolymer

Bentonite

Bentonite has been widely applied for drilling purposes due to its high swelling tendency [13]. In this study, Betonite API, known as drilling mud in constructing Barrette piles and diaphragm walls, was used. The product is manufactured according to the standards of the American Petroleum Institute. Bentonite API has the soil properties of PL = 105 %, LL = 350 %, Gs = 2.73.

Gellan gum

Gellan was produced by the bacteria Sphingomonas (formerly Pseudomonas) elodea [14], was discovered in 1978, and commercially distributed in the USA and Japan. Gellan gum is a linear, anionic exopolysaccharide, with the repeating unit consisting of α-L-rhammose, β-D-glucuronate, in the molar ratio 1:2:1 (Fig. 1) [15]. The preparation of gellan gum gels is a temperature-dependent process. Therefore, to obtain a clear gellan gum solution with low viscosity, a heating temperature of higher than 95 °C is needed, followed by the cooling process at room temperature allows changes in biopolymer chains that induce coil-to-helix transition. In this study, low acyl gellan gum biopolymer was supplied by Sigma Aldrich (CAS No. 71010-52-1).

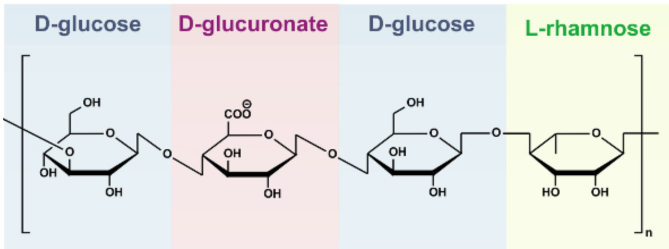


Fig. 1. Structure of low-acyl form of gellan gum [15]

Gellan gum-treated bentonite

To prepare thermo-gelated gellan gum-treated bentonite mixtures, dry gellan gum was first dissolved and hydrated in distilled water heated up to 200 °C, obtaining varying gellan gum concentration to the mass of water (m_G/m_W) of 0, 2, 3, 4, 5, 6 and 7%. It is observed that gellan gum concentration greater than 7% could not form a homogenous mixing with bentonite. Therefore, 7% was considered the maximum concentration used in this study.

The bentonite powder was dried at 105°C until it reached a constant mass. After that, the dry bentonite powder and the hot gellan gum solution were uniformly mixed at the initial water content w of 500% to form a uniform gellan gum-bentonite slurry.

After mixing, the hot gellan gum-bentonite mixtures were immediately placed into cubic molds made of stainless steel having inner dimensions of 35 mm width, 35 mm length, and 35 mm depth for the water durability test and unconfined compression test. The dry density values of the specimens were 0.327 ± 0.03 g/cm3. The specimens were named as shown in Table 1.

Table 1. Labels for specimens was tested in this study

Conditions	Gellan gum concentration [%]						
	0	2	3	4	5	6	7
Initial	M00	M02	M03	M04	M05	M06	M07
1 day of drying	M10	M12	M13	M14	M15	M16	M17
3 days of drying	M30	M32	M33	M34	M35	M36	M37

2.2 Unconfined compression test

Unconfined uniaxial compressive strength (UCS) testing was performed using a Unconfined compressive apparatus (Fig. 2). The strength tests were conducted on the cubic specimens in two conditions: initial condition (i.e., after 6 hours cooling down, room temperature of 20±1°C) and dried conditions. Regarding drying conditions, the specimens were left in the oven for 1 day and 3 days at 30°C, implying a period and an outdoor temperature that the soil may experience as it is used in emergency response in practice. The axial strain was controlled at a medium rate of 1.7 %/min [16, 17]. Generally, the UCS is taken as the peak value of the axial stress and strain curve; however, if any sample does not show a peak, stress at 15% strain is taken as the UCS value [17]. The maximum strength and the stress-strain behaviors were obtained by averaging three different measurements for a single condition.

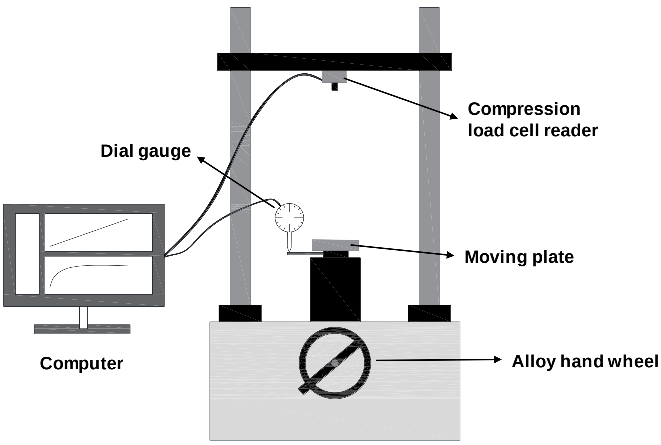


Fig. 2. Scheme of Unconfined Compression apparatus

3 Results and discussions

3.1 Effects of gellan gum concentration on unconfined compressive strength of bentonite slurry

Figs. 3, 4 and 5 show the UCS (stress) – strain curves of bentonite with and without treated by gellan gum. For the gellan gum-treated soils in the current study, all the soil specimens did not show a peak, and the stresses corresponding to 15% strain were taken. At initial condition, untreated and 2% gellan gum treated-bentonite could not be strong enough to stand for the UCS test. In other words, 2% gellan gum could not significantly enhance the strength of bentonite slurry. However, as the slurry was treated with 3% and higher gellan gum concentration, the UCS developed with the increase of axial strain (Fig. 3). This trend was observed for all specimens with thermal curing time of 1 day and 3 days (Figs. 4 and 5).

The UCS behavior of the gellan gum-treated bentonite is consistent with the varying concentration of gellan gum gels in the clay. The higher gellan gum concentration renders higher compressive strength values for the soil at both initial and drying conditions. At the initial condition, the UCS increased from zero to 1.07 kPa as bentonite was treated with 4% gellan gum. Then, it reached up to 55 kPa for 7% gellan gum-treated bentonite (Fig. 6). When the soil objected to 1-day drying, the UCS increased by approximately 64 kPa from zero. Regarding 3-day dried specimens, the UCS of 7% treated bentonite (74.52 kPa) was 16 times stronger than that of the untreated (4.67 kPa).

At all the gellan gum concentrations, the UCS increased with curing time. The untreated bentonite was strengthened after 3 days of drying with the UCS of 4.67 kPa. The significant enhancement in UCS could be seen for the case of 3% and 4% gellan gum treatment. The strength of 3% treated bentonite reached 10 times (1052%) and 18 times (1816%) greater after heating cure of 1 day and 3 days respectively. The UCS of bentonite treated 4% increased 17 times (1786%) and 35 times (3532%) higher than that of uncured specimens after 1 day and 3 days being dried (Fig. 7). However, the increase rate of strength started to reduce with gellan gum higher than 5% regardless of curing day (Fig. 7).

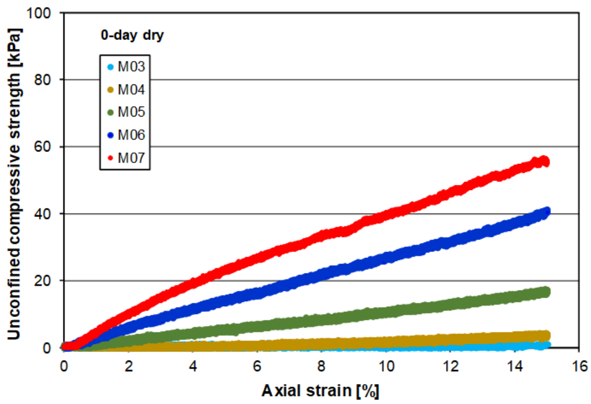


Fig. 3. Stress strain plot of gellan gum- treated bentonite at initial condition

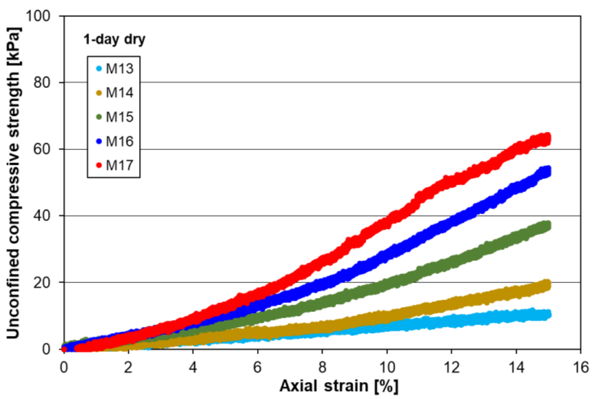


Fig. 4. Stress strain plot of gellan gum- treated bentonite after 1 day of drying

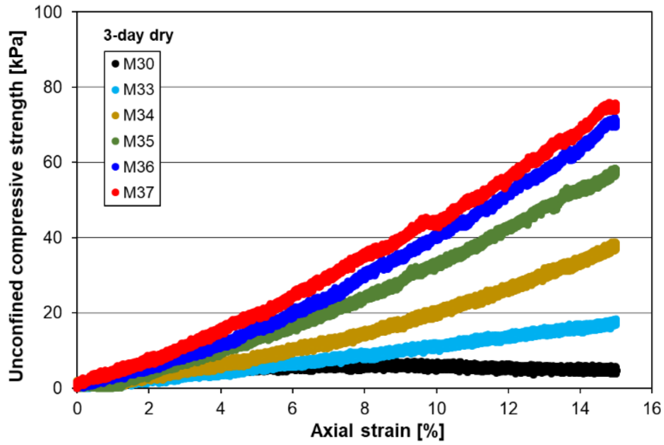


Fig. 5. Stress strain plot of gella gum- treated bentonite after 3 days of drying

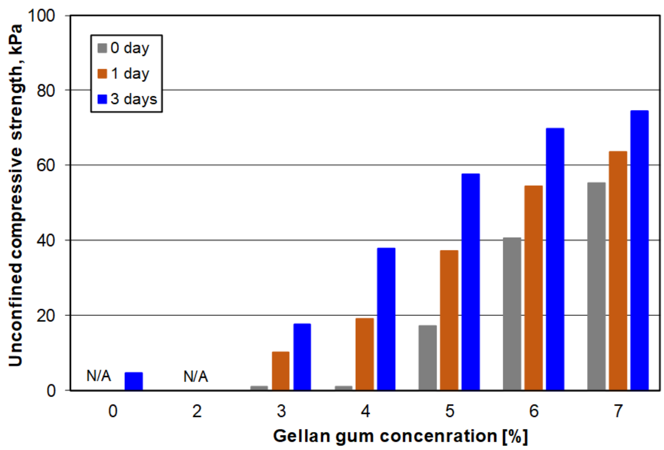


Fig. 6. Unconfined compressive strength against gellan gum concentration

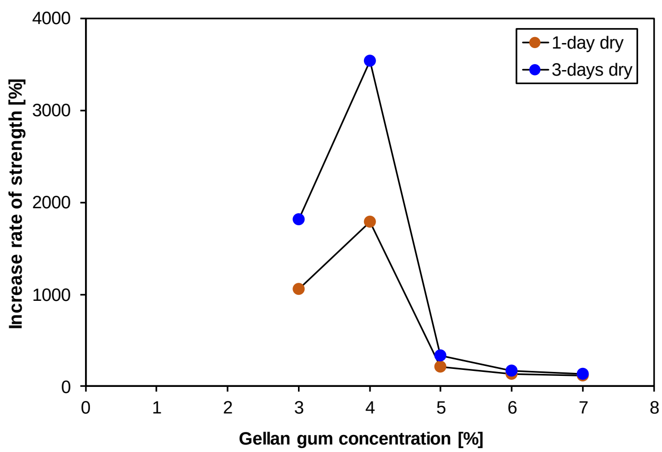


Fig. 7. Strength increase rate of specimens with different gellan gum concentrations under varying thermal curing time

3.2 Reinforcement mechanism of gellan gum-treated bentonite

Figure 8 shows the predicted reinforcement mechanism between gellan gum biopolymer and bentonite. The bentonite particles are connected by the gellan gum hydrogel to form a table structure via the fact that anionic gellan gum monomers attach to positively changed bentonite particle edges and enhance plate particle stacking [18]. The direct interaction between gellan gum and bentonite particles enhanced the inter-particle bondings of the bentonite, which governed a significant improvement in strength during compression. Therefore, at the initial state (room temperature, 20±1°C), the soil strength increases with gellan gum concentration up to 7%- (maximum concentration obtained in this study).

As the soil is under the thermal curing process, water loss occurred in gellan gum gels and bentonite particles, which boosted adhesive bonding in soil. The loss of water can be expressed via the decrease of soil weight with time (Fig. 9). The longer the curing process is, the stiffer the gellan gum film and bentonite were. Therefore, the given temperature can be considered an impacting factor for enhancing soil strength. For gellan gum with 5% and higher concentration, the change in gellan gum and bentonite interaction might not be too significant to observe the strength enhancement as the soils were under varying thermal curing time.

Regarding 2% gellan gum-treated bentonite, the initial strength could not be obtained because of its slurry state after cooling down, which proves a clue that there is a minimum amount of gellan gum used for strength enhancement of bentonite slurry. Lower than 2% concentration, gellan gum could not facilitate enough bonding to strengthen the bentonite slurry; therefore, 2% treated bentonite could not hold its shape after removing the mold (Fig. 10). Therefore, the soil was deformed as it was heated at 30 °C in the oven.

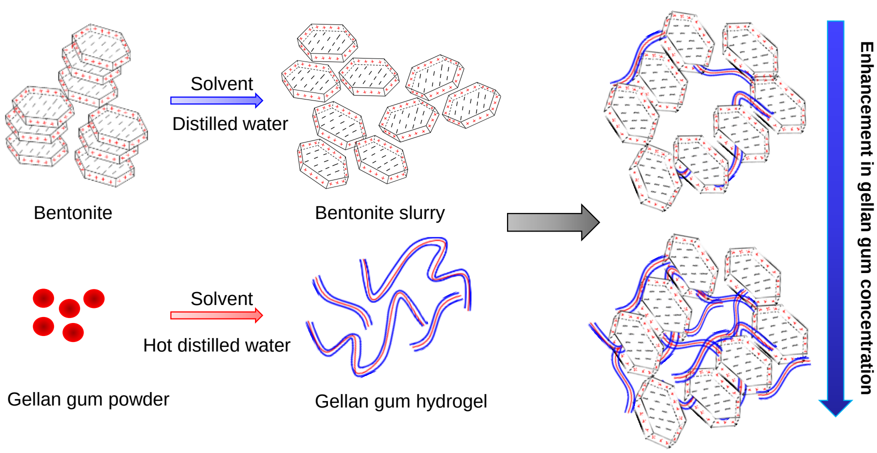


Fig. 8. Schematic diagram of bentonite – gellan gum interaction

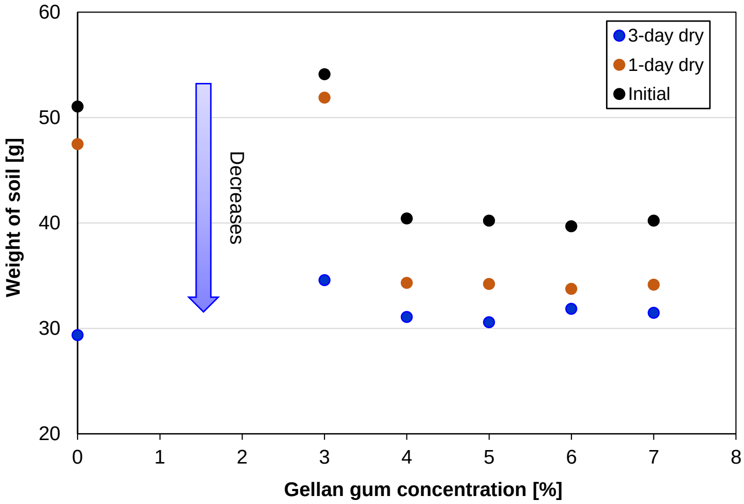


Fig. 9. Decrease in soil weight due to water loss during thermal curing

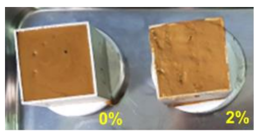
Conditions	**0 %**	**2 %**
(a) Right after molding samples		
(b) After 6 hours of cooling down		
(c) After 1-day dry		

Fig. 10. The deformation of 2% gellan gum-treated bentonite during curing

The improvement of stability of bentonite slurry using gellan gum biopolymer greater than 2% prove that the modified bentonite introduced in this study can be directly used as an emergent engineering barrier at where the soil stabilization at an excavation need to be concerned. Furthermore, as the in situ temperature ranges from 20 to 30°C, 5% gellan gum biopolymer is highly recommended for practical application in terms of economic feasibility.

4 Conclusions

The UCS tests on gellan gum–treated bentonite with gellan gum concentration (i.e., 0, 2, 3, 4, 5, 6 and 7%) and curing times (room temperature and 30°C). The test results and reinforcement mechanism are analyzed to draw the conclusions summarized as follows:

1. The UCS properties of bentonite slurry can be effectively improved by gellan gum biopolymer. The thermal curing times and gellan gum concentration are essential factors to consider. At initial condition, it is impossible for bentonite slurry specimen to be tested with unconfined compressive conditions. Whereas, the thermal curing time is longer than 24 hours, a good reinforcement effect will be achieved. This thermal effect on strength of bentonite is not shown on 2% gellan gum concentration.

2. Two percents (2%) of gellan gum biopolymer shows no effects on strengthening bentonite slurry; whereas, 5% of gellan gum is considered the optimal gellan gum concentration for practical application.

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