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SHEAR STRENGTH CHARACTERISTICS OF CALCIUM OXIDE AND GUAR GUM TREATED LOOSE PETOBO SILTY SAND

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ABSTRACT
This article presents the shear strength characteristics of Petobo Silty Sand which are treated with Calcium Oxide and Guar Gum. The purpose of this experimental works is looking for other binding agents to replace the application of cement which is considered not an environmentally friendly material. The shear strength of treated soils was examined using the direct shear test. Guar gum and Calcium Oxide provides additional cohesion to Petobo silty sand. The cohesion and internal friction angle could increase to about 900 kPa and 47.5°, respectively. The treated sample also shows the dilation behavior in dry conditions. However, after 24 hours soaking period, the soil behavior returned to the contraction behavior. This behavior is unfavorable in the case of the treated sample below the groundwater table. Hence, these two binding agents are effective for dry soil conditions. In addition, Scanning Electron Microscope images of treated silty sand were obtained which aims to examine the microscopic behavior of the fibers and matrices that were formed through the hydration process.
Keywords : *Shear Strength, Soil Behavior, Guar Gum, Calcium Oxide, Scanning Electron Microscope (SEM) Images*

1. Introduction

On September 28, 2018, the Palu-Donggala earthquake struck Palu, Central Sulawesi, Indonesia. In certain regions, a large-scale liquefaction phenomenon occurred, resulting in significant casualties and devastation. The Petobo region of the city saw the most severe liquefaction after the earthquake, which was followed by flow slides. Petobo flow slide liquefaction damaged an area of roughly 1.64 km^2. The damage was severe due to the densely populated area (Mason et al., 2021; Kusumawardani et al., 2021; Jalil et al., 2021). Besides the geomorphology of this location, the soil itself is also susceptible to liquefy during an earthquake. Hence, soil improvement could be an alternative to prevent future events occurred.

Although cement is beneficial in terms of stabilizing, it has a significant environmental impact, such as CO_2 emissions. For every tonne of cement produced, about 1 tonne of CO_2 is produced (Thangaraj & Thenmozhi, 2013). Cement was responsible for 8% of global CO_2 emissions (Le Quéré, 2016). Quicklime has lower CO_2 emissions with 0.2-0.45 tonne CO_2 per tonne (European, 2001). Both quicklime (CaO) and hydrated lime (CaOH), were also used to bind soil particles, which has a stabilizing effect. The quicklime was proven to increase the shear strength of fine-grained soil (Di Sante et al., 2019). Previous studies on soil stabilization techniques using environmentally friendly materials such as agar, gum, and other organic material were conducted to reduce the environmental impact of common stabilization materials such as cement. Previous studies that used biopolymers such as agar, xanthan gum, guar gum, and glucomannan have been performed for soil improvement without cement (Lim et al., 2021; Smitha & Sachan, 2016; Ayeldeen et al., 2016; Patel & Shah, 2016; Chang et al., 2015; Lee et al., 2017). Xanthan gum matrices provide a significant strengthening effect on treated soil through inter-particle relations within the soil (Lim et al., 2021; Chang et al., 2015; Albrecht et al., 2020). Guar gum was used to enhance physical characteristics such as shear strength parameters and compressive strength (Ayeldeen et al., 2016; Patel & Shah, 2016). Geotechnical shear behavior of Xanthan gum-treated soil in dry conditions showed high peak shear strength. (Lee et al., 2017) Guar gum has an exceptional bonding property which provides significant improvement in terms of soil stabilization (Sujatha & Saisree, 2019). The decrease in the value of the soil shear strength occurred when the agar-treated sample is soaked. (Smitha & Sachan, 2016). According to above reviews, limited study was conducted for silty sand soil.

As mentioned, that Petobo area experienced liquefaction due to earthquake, this article proposed an environmentally solution to reduce the liquefaction susceptibility. In this article, Calcium Oxide and Guar gum were used to stabilize Petobo silty sand. Calcium Oxide and Guar Gum could act as binding agents, replacing the usage of cement. Some aspects are investigated such as the treated soil behaviors, (i.e., contraction or dilation), and the soil shear strength (i.e., soil cohesion and angle of internal friction). The apparatus used in this experimental works was the direct shear test. Moreover, the microscopic behavior of the binder agent in terms of strengthening factors (aggregate coating, pore filling, and inter-particle bonds) was observed using the Scanning Electron Microscope (SEM) test. SEM test will visually clarify the binding mechanism of the Calcium Oxide and Guar Gum.

2. Literature Review

Petobo Silty Sand

Silty sand is commonly found in the Petobo region, which contains low content of fine-grained particles (15 to 20%). The sand used in this study was obtained from Petobo in the Donggala district of Palu, Central Sulawesi. The particle size distribution of Petobo sand was obtained from sieve and hydrometer analysis, as shown in Fig. 1 (ASTM D6913, 2017, ASTM D7928, 2017). The mean particle size (D_{50}), coefficient of uniformity (C_u), and coefficient of gradation (C_c) are 0.17 mm, 9.2, and 2.10, respectively. Petobo silty sand has a specific gravity (G_s) of 2.72 (ASTM D854, 2014). Thus, Petobo sand is classified as silty sand on the unified soils classification system (ASTM D2487, 2017). The minimum and maximum dry density of Petobo silty sand are 1.30 and 1.74 respectively (ASTM D4253, 2019).

Guar gum

Guar gum is a naturally occurring polysaccharide derived from the Leguminosae plant Cyamopsis tetragonoloba. Guar gum is a popular emulsifier, thickener, and stabilizer in the food industry. Guar gum is also used in textiles, explosives, cosmetics, and even the treatment of health problems (Mudgil et al., 2011). Guar gum has pseudoplastic properties, which cause the viscosity to decrease while adding shear stress. (Patel & Shah, 2016) Guar gum has hydrophilic characteristics and is more soluble in water than other biopolymers thus making it a better stabilizer (Jang, 2020) Guar gum provides bonds between particles due to dehydration from gel formation formed in the soil particle matrix (Ayeldeen et al., 2016).

Guar Gum biopolymer has been proven to increase the shear strength of soil, where the cohesion parameters increase significantly due to the addition of Guar Gum. Guar Gum is also superior to biopolymers Xanthan Gum, Carrageenan Gum and Modified Starch (Starpol 136) in terms of increasing compressive strength, dry unit weight, CBR value, liquid limit, undrained shear strength, reduction of collapsible potential, swelling potential, durability in dry and wet conditions, and soil erosion resistance. Guar Gum is also a biopolymer that is relatively cheap and easy to obtain on the market. The general increase in soil strength is obtained from Guar Gum which fills the cavities or pores in the soil and then binding occurs between soil particles which contain metal ions and anions and Guar Gum due to dehydration of the united and hardened gel formation formed in the particle matrix. land. This is due to the pseudoplastic nature of Guar Gum, where as the viscosity decreases, the shear stress increases. However, the use of high biopolymer concentrations results in high viscosity resulting in difficulties in mixing or mixing (lack of workability) and reduces the bulk density of the soil, which means the strength of the soil as well.

Calcium Oxide

Calcium oxide (CaO or quicklime) is produced by burning raw lime at a temperature of approximately 900°C. When quicklime is mixed with water, it produces heat and transforms into quenched lime (CaOH, calcium hydroxide). When lime and water react with soil minerals, a strong gel, calcium silicate, is formed that binds grains or soil particles. It is possible to stabilize the soil by adding burned limestone products such as calcium oxide or calcium hydroxide (hydrated lime) to it. It is known that stabilization with quicklime shows a more effective stabilizer of soil than hydrated lime (Bell, 1993).

3. Research Methods

Soil mixture preparation

Specimens for direct shear testing were prepared through dry-mixing by mixing the dry ingredients first before adding the water (Chang et al., 2015). A concentration of 1% for each binder and water content of 20% was used throughout this experiment. For example, to prepare three specimens for one series of direct shear testing, 350 gr of untreated silty sand was mixed with 3.5 gr for each binder (Guar gum and/or calcium oxide) then 70 gr of water was added to the dry ingredients. The prepared specimens were cured at room temperature of 24 ± 2 °C for different curing periods (7 days and 14 days). In addition, the oven-dried samples were also prepared by putting the samples into a 100°C oven for 24 hours.

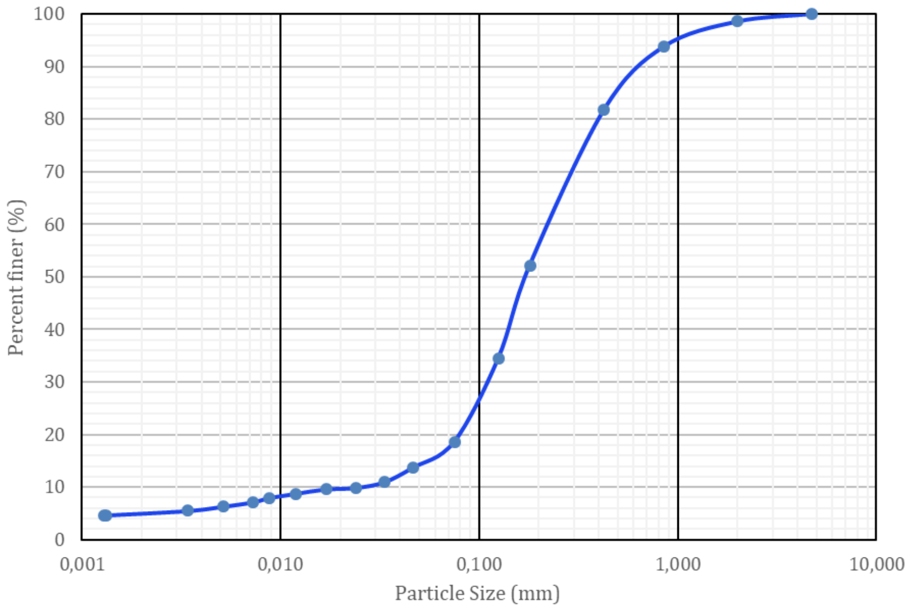


Fig. 1. Grain-size distribution for Petobo Sand

Mixed soils are then transferred to a mold and could be seen in Fig. *2*.

Fig. 2. Mixing process (a) dry mixing of binder and sand (b) water was added (c) molding process

Test Procedure

To obtain the shear strength parameters of the treated sand, all of the specimens were put in the shear box then a direct shear test was performed under three different loads (1.5 kg, 3kg, and 4.5kg) (ASTM D3080, 2012). A constant deformation rate of 0.025 mm/min was used in the direct shear testing of treated sand. Three series of direct shear testing with different curing times were performed on binder-treated Petobo silty sand. In addition, the oven-dried samples were also soaked for 24 hours inside the shear box to investigate the effect of sample wetting on the shear strength. The experimental plans are listed in Table 1. Furthermore, Scanning Electron Microscope (SEM) tests were performed on the oven-dried samples, to evaluate the inter-particle interaction, pore filling, and aggregate coating effect of the binder on the soil.

Table 1 - Experimental plans for calcium oxide and or guar gum treatment of Petobo sand

Series	Binder	Curing time
T1	Calcium oxide	Oven-dried for 24h Air dried for 7 days and 14 days
T2	Guar gum	Oven-dried for 24h Air dried for 7 days and 14 days
T3	Calcium Oxide and Guar gum	Oven-dried for 24h Air dried for 7 days and 14 days
After soaked for 24 hours		
T4	Calcium oxide	Oven-dried for 24h
T5	Guar gum	Oven-dried for 24h
T6	Calcium Oxide and Guar gum	Oven-dried for 24h

4. Results and Discussions

The shear strength of the soil is defined as the resistance of the soil to shear which is the result of friction and the bond between the particles (cohesion). For soils that are given additives, the shear strength of the soil is expected to increase due to cementation which affects the bond between particles. The soil shear strength of Petobo silty sand mixed with different mixtures of Calcium Oxide and or guar gum biopolymer is examined with the same concentration of binder which is 1% of the weight of dry soil. The untreated Petobo silty sand has a friction angle of 38.2° and zero cohesion ($c = 0$). The increase in stability from the addition of a mixture of Guar gum and/or Calcium Oxide on Petobo Sand soil can be seen from the results of direct shear testing on Petobo Sand soil that has been mixed with Calcium Oxide and/or Guar Gum can be seen in Table 2. In general, the cohesion of the treated samples increases, while the friction angle has no significant differences from the untreated samples. The determination of cohesion and internal friction angle is according to the Mohr-Coulomb failure criterion. The detailed discussions are shown in the next section.

Table 2 - Shear strength of Petobo Sand treated with Calcium Oxide and or Guar gum

Binder	Curing method	Peak Shear Stress (kPa)			c (kPa)	f (°)
		Normal Load: 1.5 kg	Normal Load: 3.0 kg	Normal Load: 4.5 kg		
Calcium Oxide	Oven Dried	75.16	123.18	150.43	41	34.7
	7 days	104.16	133.45	163.42	75	28.3
	14 days	114.55	181.96	191.72	85	34.6
	Soaked	45.83	82.50	127.52	6	35.8
Guar Gum	Oven Dried	519.55	711.20	939.41	321	74.6
	7 days	143.45	183.43	260.20	81	46.4
	14 days	439.09	472.96	488.05	419	23
	Soaked	81.59	85.46	107.09	67	12.5
Calcium Oxide	Oven Dried	963.43	1008.1	1089.7	900	47.5
+	7 days	190.84	226.03	271.79	151	35.3

Guar Gum	14 days	381.90	473.51	548.19	308	55.3
	Soaked	48.81	67.03	94.82	26	21.9
Untreated Soil		42.13	86.97	123.50	0	38.2

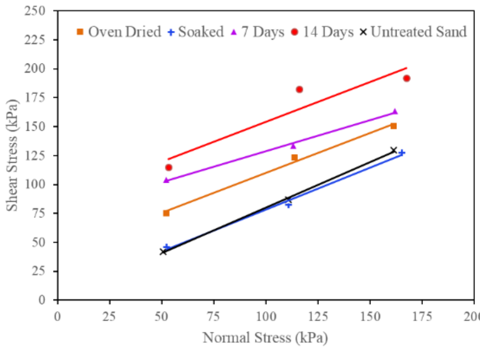
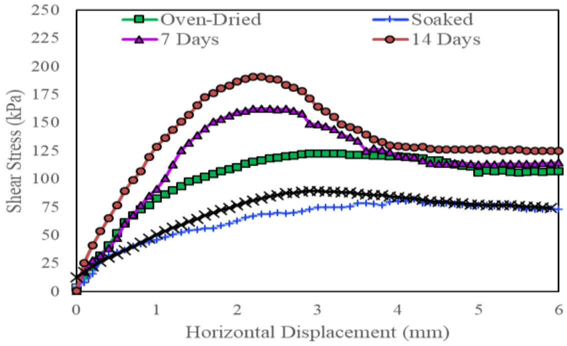
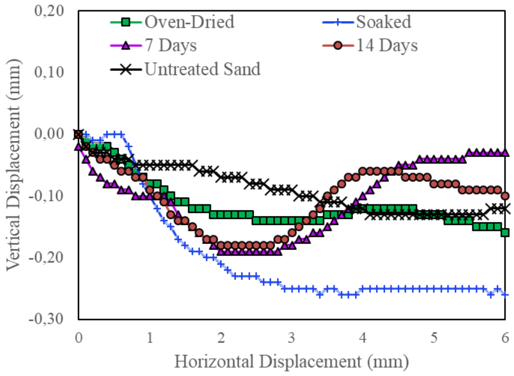


Fig. 3. Failure Envelope Of Calcium Oxide Treated Petobo Sandy Soil With Different Curing Times And Methods

The shear stress-horizontal displacement and vertical displacement curve of calcium oxide-silty sand mixtures are obtained through the direct shear test (Fig. 4). Strain-softening and dilation behavior can be seen on the air-dried samples which the shear stress value tends to drop significantly as it reaches its peak. On the other hand, the soaked and oven-dried samples have a strain-hardening and compression behavior in which their shear stress value does not experience a significant drop when it reaches its peak.



(a)



(b)

Fig. 4. Direct Shear Test Result for Calcium Oxide treated Petobo Sand with 3 kg load (a) Stress-strain curve (b) Vertical displacement

Guar gum Mixture

The addition of guar gum to the Petobo silty sand showed an increase in cohesion for each curing variation, but not the friction angle. Fig. 5 shows the failure envelopes of the sample mixture of Petobo silty sand and guar gum. It seems that Guar gum does not interact chemically with sand. Therefore, the cohesion values obtained from direct shear tests are mainly due to guar gum matrices Air-dried and oven-dried samples have a significant increase in terms of cohesion value indicating that guar gum matrices have an exceptional bonding property (Sujatha & Saisree, 2019; Ayeldeen et al., 2016). Soaked samples have a cohesion value of 67 kPa and a 12.5° friction angle. This indicates guar gum matrices are still present after being soaked for 24 hours. The failure envelope of oven-dried samples shifts upwards as its friction angle value increased significantly.

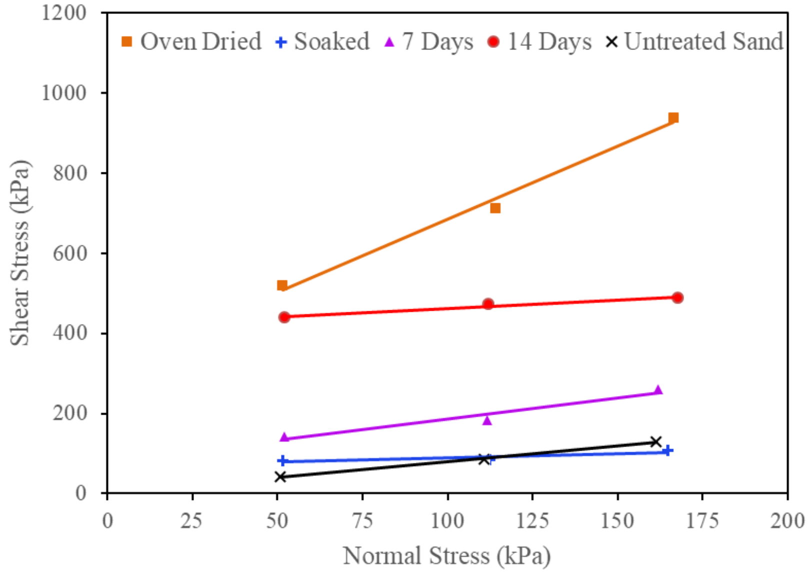
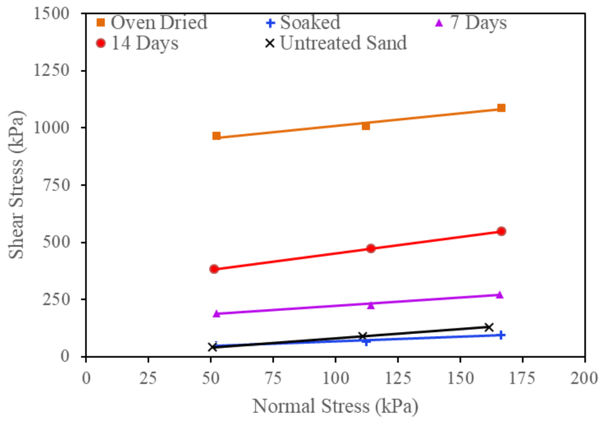


Fig. 5. Failure Envelope of Guar gum treated Petobo Sandy Soil with different curing times and methods

Furthermore, Fig. 6 shows the shear stress-horizontal displacement and vertical displacement curves that are obtained through performing direct shear tests. Dilation and decrease in shear stress value when it reaches its peak for the oven-dried and 14 days air-dried samples implies that it has strain-softening behavior. Strain-hardening behavior can be seen on the 7 days of air-dried and soaked samples which the shear stress value tends to drop as it reaches its peak.

Calcium Oxide and Guar gum Mixture

The purpose of mixing Calcium Oxide and Guar gum is to check whether both agents could yield better performance if they work together. Failure envelopes of Petobo silty sand which are mixed with guar gum and calcium oxide can be seen in

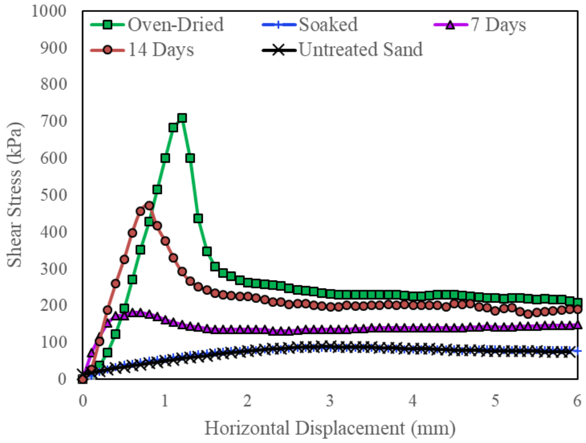


. An increase in cohesion value occurred on all of the unsoaked samples, with 900 kPa at its highest on the oven-dried sample. The soaked sample has a cohesion value of 26 kPa, which decreased significantly when compared to the oven-dried sample. This indicates that the guar gum and calcium oxide matrices were dissolved thus leaving behind a small amount of cohesion left.

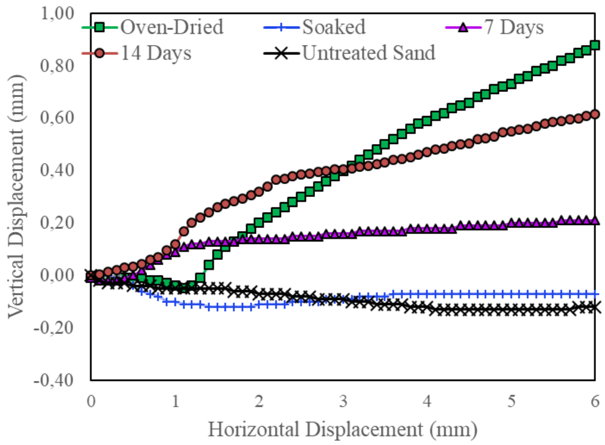
Shear stress-horizontal displacement and vertical displacement curves are shown in Fig. 8. Strain-softening and dilation behavior can be seen in 14 days air-dried and oven-dried samples. Its shear stress value drops significantly as it reaches its peak. Soaked and 7 days air dried samples did not have a significant decline in shear stress value. This implies that it has strain-hardening behavior.

Microscopic Behavior of Treated Petobo Sand

Scanning electron microscope tests (SEM) were conducted to observe the microscopic behavior of the binder-treated soil. Microscopic behavior such as aggregate coating, pore filling, and inter-particle bonding was responsible for the occurrence of cohesion in sandy soil which in its natural state was cohesionless (Patel & Shah, 2016). From Fig. 9, it can be seen that guar gum and calcium oxide matrices were present between and around soil particles thus giving its artificial cohesion.



(a)



(b)

Fig. 6. Direct Shear Test Result for Guar gum treated Petobo Sand with 3 kg load (a) Stress-strain curve (b) Vertical displacement

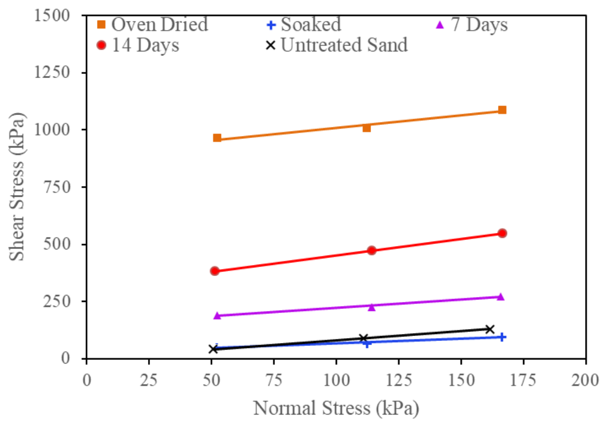


Fig. 7. Failure Envelope Of Guar Gum And Calcium Oxide Petobo Sand Mixture With Different Curing Times And Methods

Discussion

Main Strengthening Factor

The results of direct shear testing of samples mixed with calcium oxide and/or guar gum showed an increase in the value of the shear strength parameters when tested in dry conditions without being soaked. This is due to the bond between sand soil particles caused by the binding layer of Guar gum and or Calcium Oxide biopolymers (Chang et al., 2015; Lee et al., 2017). The most significant increase was found in the sand soil samples which were mixed with guar gum and calcium oxide and dried in an oven at a temperature of 100°C for 24 hours which had a cohesion value of 900 kPa and a friction angle of 47.5°.

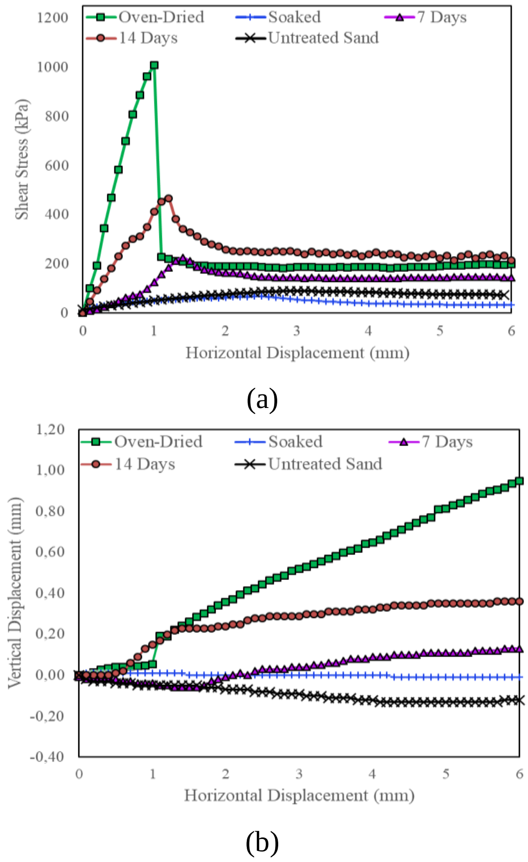
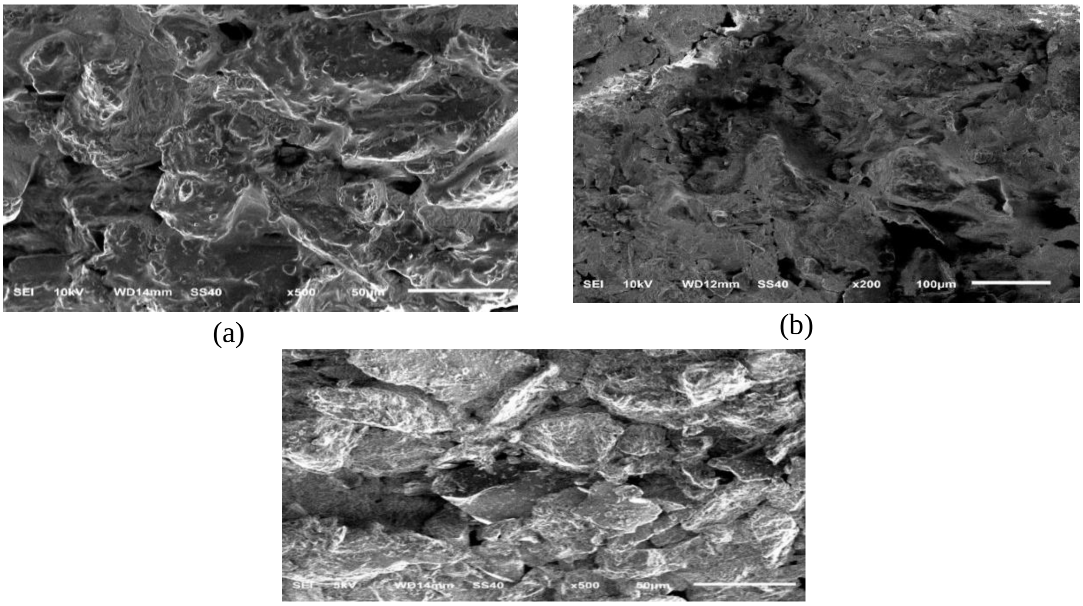


Fig. 8. Direct Shear Test Result for Calcium Oxide and Guar gum treated Petobo Sand with a load of 3 kg (a) Stress-strain curve (b) Vertical displacement



(a) (b) (c)

Fig. 9. Scanning Electron Microscope test results for (a) Guar gum treated sand (b) Calcium Oxide treated sand (c) Guar gum and Calcium Oxide treated sand

Petobo silty sand which has been mixed with a 1% concentration of guar gum and cured for 7 days has an improvement in cohesion value of 82 kPa, and 8.2° for the internal friction angle. On other hand, Albrecht et al, 2020 observed the effect of Guar gum with 1% concentration on Ottawa Sand which is poor-graded sand and cured for 7 days. The results showed that the sample with 7 days of curing have an increase in cohesion value of 72 kPa and internal friction angle of 2°. Stabilization of sandy soil with Guar gum tends to have a much increase in cohesion value when it is mixed with well-graded soil such as Petobo silty sand. This finding matched with previous research from Chang et al, 2015 that concluded that well-graded size distribution type of soil showed better-strengthening factors when mixed with biopolymers.

The effect of water soaking on the shear strength of calcium oxide-treated sand shows poor results such as cohesion and friction angle value falling close to untreated sand. Guar gum-treated sand on the other hand still has its cohesion of 66 kPa. This indicates that not all of the guar gum matrices were not fully dissolved. The rehydration process aims to assess the feasibility of the binder in later practice (Smitha & Sachan, 2016).

Soil shear strength behavior of the samples that were tested on the direct shear stress could be observed from the stress-strain curve. Most of the treated Petobo sand samples showed strain-softening behavior in which the shear stress value drops when it reached its peak. This behavior is similar to dense sandy soil. Previous studies also show that biopolymer-treated sandy soil has strain-softening behavior when sheared in dry conditions (Smitha & Sachan, 2016) (Lee et al., 2017).

5. Conclusion

The soil stabilization method using Guar gum and or Calcium Oxide biopolymer aims to increase the shear strength parameter of the original soil. Petobo silty sand soil, which is well-graded and contains 18% of fine grains, is used in this study. This soil experienced liquefaction in 2018. Guar gum and Calcium Oxide biopolymers were chosen as binder mixtures due to their properties that can hydrate and form bonds between particles. Petobo silty sand soil was mixed with Guar gum and Calcium Oxide biopolymers using different variations of curing time. The addition of Guar gum and Calcium Oxide biopolymers was proven to increase the parameters of the shear strength of Petobo silty sand, especially in cohesion value. The increase in the shear strength parameter was caused by the presence of bonds between the particles of the binder mixture that had undergone a hydration process. Guar gum and Calcium Oxide biopolymers provide additional cohesion to sandy soils which have non-cohesive naturally. The addition of

Guar Gum and/or Calcium Oxide could change the soil behavior and becomes dilation. It could be said that the behavior of the treated sample is similar to dense sandy soil. However, the behavior becomes contraction when the treated sample is soaked in water for 24 hours. Hence, these two binding agents are only effective for dry soil conditions.

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