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Strength Improvement of Cement Stabilized Soil by Binder Mineral Additive

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ABSTRACT

The stability of the underlying soil significantly influences pavement construction for long-term performance. Subgrades often have a low bearing capacity in order to achieve adequate capacity under traffic loading. This study presents the strength and bearing capacity of the road pavement by utilization of a binder mineral powder for soil-cement stabilization. The Unconfined Compression Test (UCT) and California Bearing Ratio (CBR) test conducted at optimum moisture content (OMC) and maximum dry density (MDD). The dry-wet cycle (D-W) test also conducted to observe the strength behavior of the stabilized soil. The results show that the mix of the binder mineral and soil-cement, resulting in higher strength and bearing capacity. The strength characteristics of stabilized soil with binder mineral tend to decrease for the initial cycle slightly. In contrast to untreated soil, the strength significantly decreased by subjected to the wet-dry cycle test. These characteristics change of stabilized soil may lead to potential using of binder mineral as an additive for soil-cement stabilized.

1. Introduction

The most common techniques usually used to overcome the problems created by problematic soils involves the use of mixtures with a cementitious binder. Generally, these binders are cement or lime, which bind the soil particles together through chemical reactions. Some researchers conducted study by using admixtures to improve the mechanical properties of the soil. Soil-cement is widely used as a base material for many construction projects, i.e. pavement of highways, embankments, slope protection and foundation stabilization. Utilizing of soil-cement has proven to be cost-effective (Khattak and Alrashidi, 2006). Utilization of short fiber in cement stabilized clayey soil increased the strength of stabilizes soil significantly (Tang et al., 2007; Harianto et al., 2008). The ductility significantly improves without changing the compressive strength by the existence of fiber in the cement-soil mixture. The existence of fiber in the cement-soil mixture can suppress the development of crack formation during the Unconfined Compressive Strength (UCS) test (Liu and Starcher, 2013).

The utilization of cement has severe environmental impacts, as it involves using vast amounts of fossil fuels as well as being responsible for the emission of more than 5% of all the carbon dioxide released worldwide (Provis and Deventer, 2014). Therefore, an attempt to reduce using cement in soil stabilization is increasing. Recently, the most common soil improvement techniques by using lime as a stabilization agent. A result of lime stabilization, clay particles stick to each other and form larger particles (Broderick and Daniel, 1990). The changes are observed in the soil, the optimum moisture content (OMC) values

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increase, densities decrease, plasticity indices reduce and CBR values increase. The recent study of Alkaline Activator of Fly-ash in soil stabilization. The results by comparing Alkaline Activator and cement-based binders have proved the technical and economic viability (Rao and Acharya, 2014; Sukmak et al., 2015).

An alternative to cement for soil-stabilization applications is proposed, based on the activation of industrial waste—coal burning fly ash (FA). Alkaline activation (AA), which is also known as geo-polymerization when low-calcium precursors are used (Davidovits, 1991), can be described as a reaction between aluminosilicate materials and alkali or alkali-based earth substances. Soil-cement and alkaline-activated specimens show a similar type of cementation, observed by strength significantly increased. The main difference between the two binders is the various curing rate, with cement shows a significant strength improvement at an earlier age and stabilizing after curing for 28 days (Rios et al., 2016).

Some other researchers, such as Estabragh et al. (2011) and Anagnostopoulos (2007) suggested that acrylic resin as an agent to a soil-cement mixture increased the mechanical properties. Improvement in soil properties (UCS and CBR) also reported by Joel and Agbede (2011). Mechanical-cement stabilization was adopted to increase the strength of laterite soil as a flexible pavement material. Several methods are generally applied to improve and modify the strength properties of these problematic soil. Bearing capacity (CBR) improvement also reported by Mengue et al. (2017), the fine-grained lateritic soil treated with cement improved by mechanical effort. In this paper, an alternative binder mineral additive for soil-cement stabilization is proposed. The results of an experimental of compressive strength and bearing capacity of soil-cement mixtures with various binder mineral additives are presented. The effects of binder mineral additives on the strength characteristics and bearing capacity is studied and discussed.

2. Materials and Methods

2.1. Materials

The soil sample used was obtained from a borrow pit in the eastern part of Makassar city (located between $5^0$13’52” S and $119^0$29’57” E) by method of disturbed sampling. The soil samples were transported to the laboratory in sealed bags. The Portland cement type 1 was used to form soil-cement mixture. In order to identify the mineral content of the additive, x-ray diffraction analysis was carried out on the sample mineral passing No. 200 sieve. The chemical compositions of binder mineral are presented in Table1. According to **Table 1**, the binder mineral mainly consists of cristobalite, bromine, chlorine and lime. A small amount of strontium peroxide and magnetite was found. These chemical compositions are commonly present in binder mineral.

Table 1. Chemical composition of binder mineral

Compound	Formula	Unit	Value
Cristobalite	O_2Si	%	45.6
Bromine	Br	%	26.6
Chlorine	Cl_2	%	14.8
Lime	CaO	%	7.1
Strontium Peroxide	O_2Sr	%	2.8
Magnetite	Fe_3O_4	%	1.6
Oxygen	O_2	%	1.5

2.2. Methods

The soil sample was air dried for one day prior to testing in order to simulate the fields condition. This procedure conducted due to the different environment, usually affected the index properties of the soil samples (Moh. and Mazher, 1969). The physical and mechanical properties of soil sample are summarized in **Table 2**. The engineering properties of the soil sample were determined in accordance with American Society for Testing and Materials (ASTM, 1992).

The Unconfined Compression Test (UCT) and California Bearing Ratio (CBR) test conducted at optimum moisture content (OMC) and maximum dry density (MDD) obtained from Standard Proctor Compaction. The additives compositions were prepared based on the dry weight of soil sample. The physical and mechanical tests were conducted on untreated soil as well as soil-cement stabilized soil. According to Millard (1993) cement-treated soils are usually observed by the UCS test. The application of CBR test for the evaluation of cement requirement is

Table 2. Engineering properties of soil sample

Designation	Standard Method (ASTM)	Value	Unit
A. Physical Properties			
Specific Gravity	D-162	2.65	
Water Content	D-2216-98	38	%
Soil Classification :	C-136-06		
a. USCS		CH	
b. AASHTO		A-7-5	%
Atterberg Limit			
a. Liquid Limit (LL)	D-423-66	65	%
b. Plastic Limit (PL)	D-424-74	34	%
c. Plasticity Index	D-4318	32	%
B. Mechanical Properties			
Standard Proctor Test	D-698		
a. Optimum Moisture Content (OMC)		31	%
b. Maximum Dry Density (MDD)		13.7	KN/m^3
Unconfined Compression Test (UCT)	D-633-1994		
a. Compressive strength		93.2	KN/m^2
California Bearing Ratio (CBR)	D-1833		
a. Unsoaked		6.8	%
b. Soaked		2.5	%

due to the wide use of the test for pavement design in tropical areas [Transport and Road Research Laboratory (TRRL) ,1977).

Furthermore, the dry-wet cycle (D-W) test also conducted to observe the strength behavior of the stabilized soil. Cyclic wetting-drying experiments are carried out to obtain the change of the strength of the untreated and soil-cement stabilized soil. The binder mineral composition was set fixed to 2% with 0, 2, 4 and 6% of cement content respectively. Soil samples with a diameter of 50 mm and height 100 mm are prepared by using cylindrical wall samplers. Initially, the samples were cured in a air-dry condition for 14 days. The wetting-drying cycle was conducted by submerging the samples in water (tap water) until saturation (48 hours) and subsequently air-drying for 7 days. After the curing process completed, all samples are subjected to 3 cycles of wetting-drying. The weight measurement of the samples was conducted on each cycle completed.

3. Results and Discussions

3.1. Compaction Properties

An addition of binder mineral to the soil-cement mixture shows increasing values of MDD compared to untreated soil, whereas the OMC values decreased. The MDD increased from 13.7 kN/m^3 for untreated soil up to 14.8 kN/m^3 for the 6% cement-treated sample with 2% of binder mineral as shown in **Fig. 1**. Furthermore, the OMC decreased from 31.4% (untreated soil) to 27.1% for the 6% cement-treated sample mixed with 2% of binder mineral. Similar behaviour has been reported for some lateritic soil stabilized by cement (Al-moudi, 2002; Oyediran and Kalejaiye, 2009).

The increase in MDD of cement-treated soil mixed with binder mineral could be attributed to the fact that the presence of water in cement tends to lubricate the soil mixture, resulting in the denser mixture during the compaction process. Furthermore, the fine cement and binder mineral particles fill the voids between soil particles, a denser soil matrix formed. The self-desiccation of water may be attributable to the decrease of OMC in the cement-treated soil. The hydration reaction also takes place during the mixing process.

3.2. Unconfined Compressive Strength

The effect of binder mineral additive in cement-treated soil on the unconfined compressive strength behavior is shown in Fig. 2. It can be observed that the UCS increases with increasing cement content with a fixed amount of binder mineral (2% of cement content). The increasing of UCS in cement-treated soil (6% cement) mixed with binder mineral observed almost 4.5 times of magnitude compared to the untreated soil. However, the soil specimen mixed only with 2% binder mineral shown an increasing of UCS value almost 3 (three) times of magnitude for 28 days curing time. Moreover, increasing the curing time (7 to 28 days) also affected to the increasing of UCS value for all the cement-treated soil samples.

The cement treatment leads to a significant increase in UCS, especially for cement content greater than 2%. However, the cement content of 4 and 6% slightly higher in the UCS value than cement content of 2%. Increase in UCS with cement content is in good agreement with the study conducted by Osinubi (2001). Thus, cement-treated soils mixed with binder mineral additive exhibit more brittle behavior compared to untreated soil.

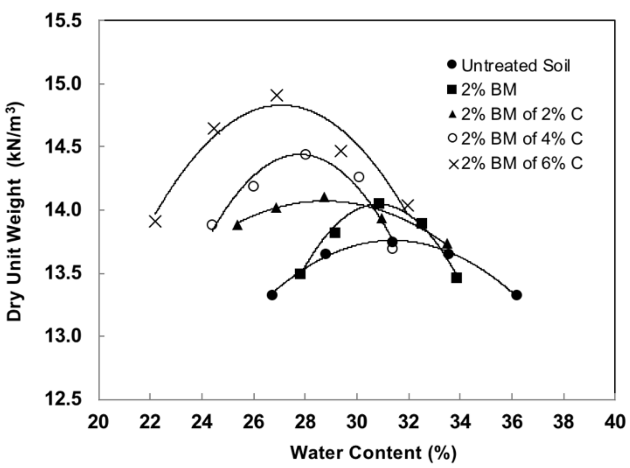


Fig. 1. Compaction characteristics of various binder mineral and cement content

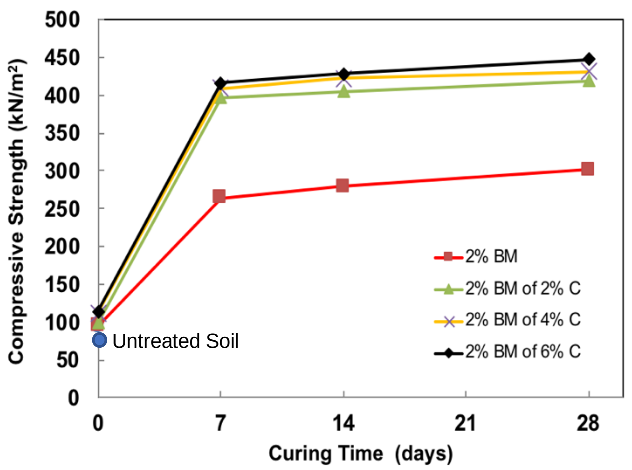


Fig. 2. Compressive strength of soil stabilized by binder mineral and various cement content

The results of UCS value indicate that the samples treated with 6% cement and mixed with binder mineral of 2% of cement content could be used as a sub-base and subgrade layer. Whereas, the samples treated with 2 and 4% cement can be used only in a subgrade layer of road pavement.

3.3. California Bearing Ratio

The CBR (unsoaked) test was carried out for the untreated and cement-treated soil. Variation of the CBR value of cement-treated soil mixed with binder mineral is shown in **Fig. 3.** Furthermore, the CBR values also affected by its curing time. The highest value was found for 28 days. It can be seen that CBRs value of the stabilized soil increasing with the addition of cement and binder mineral. The increasing of CBR value of the cement-treated soil is in good agreement with the previous study by Osula (1989) and Mengue et al. (2017). Moreover, the highest CBR value observed for the composition of 6% cement content with 2% binder mineral. The CBR increased significantly from 6.8% (untreated soil) to 28% and 39% for 7 and 28 days curing period, respectively. The similar behaviour also observed for 2 and 4% of the cement content. These values met the requirement of Indonesian National Standard (SNI-03-3438-1994) for subgrade and sub-base layer of pavement foundation. The Indonesian general specification recommended that a minimum CBR value of subgrade and sub-base are 6 and 20%, respectively.

Overall, it is observed that the addition of binder mineral on the cement-treated soil leads to an improvement of CBR value. This increase reflected an improvement of bearing capacity of the cement-treated soil mixed with binder mineral. The bearing capacity improvement is a result of the stiffening of the soil by effect of the cement hydration. The secondary process consists of reactions between soil particles and calcium hydroxide, which is released during cement hydration. This secondary process can affect the strength improvement of the soil mixture as well as reduce the plasticity and swelling potential.

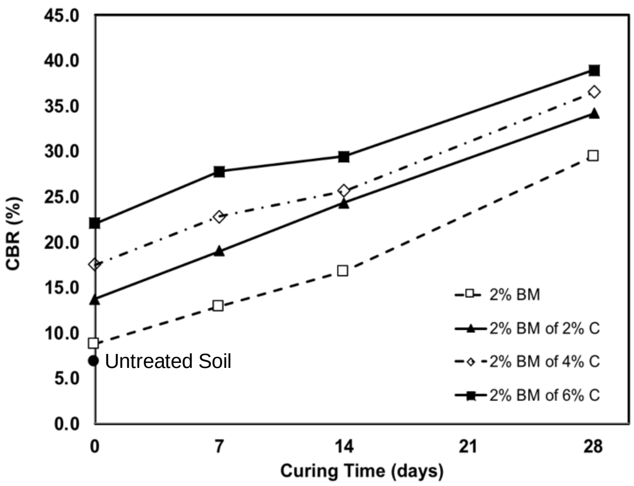
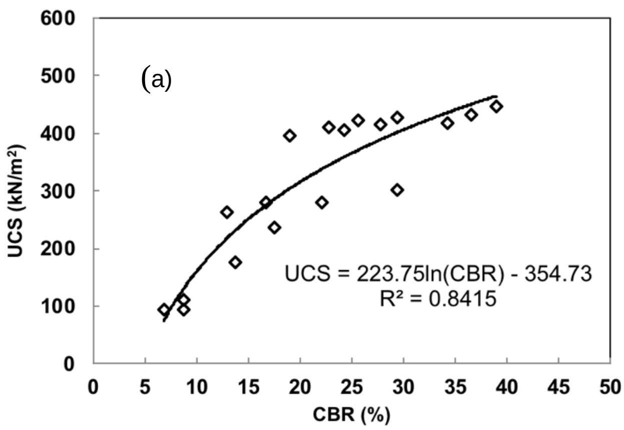


Fig. 3. CBR of soil stabilized by various binder mineral and cement

The relationships between mechanical properties are shown in **Fig. 4**. **Figure 4(a)** shows that the polynomial relationship occurs in the relationship between UCS and CBR as presented in **Eq. 1**. The good correlation exists (R^2=0.8415), which is indicated the strong relationship between parameters. The relationships between the modulus of elasticity (E) and UCS are presented in **Fig 4(b)**. The linear relationship is in good correlation (R^2=0.9212) between parameters and presented in **Eq. 2**. The fit equations for the data obtained give the regression coefficient correlations range from 0.8 to 0.9, which is indicated a reasonable correlation. The relationships obtained in this study shows a consistent trend with a previous study (Jegandan et al. 2010; Szymkiewics 2011).

$$UCS = 223.75 \ln(CBR) - 354.73 \quad [1]$$

$$E = 0.4817 (UCS) + 17.538 \quad [2]$$



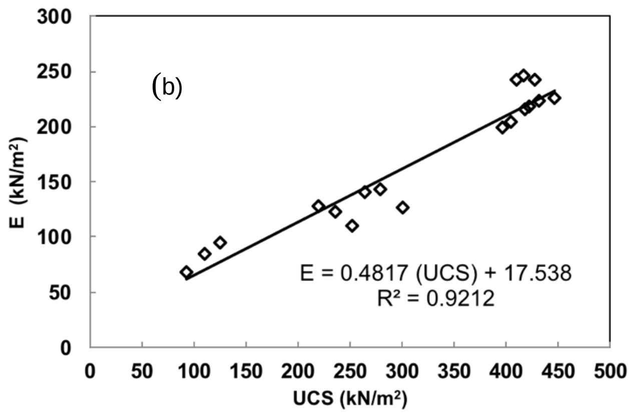


Fig 4. Relationships between parameters: (a) UCS and CBR and (b) E and UCS

The relationships shown in **Fig. 4** indicated that all the parameter values (UCS, CBR and E) increase with an increase in cement content. The trend of increasing E with addition binder mineral in cement-treated soil can be observed and mainly attributed to the formation of calcium silicate hydrate (CSH) link produced by the hydration and pozzolanic reaction, which are secondary cementitious products. Therefore, the stiffness of cement-treated soil with binder mineral additives increases significantly. These compounds form as a crystallize and harden with time, thereby improving the strength of the soil-cement mixes (Chew et al. 2004; Okyay and Dias 2010; Kamruzzaman et al. 2009). Therefore, the stiffness of cement-treated soil with binder mineral additives significantly increase. The addition of 6% cement, for instance, implies an significant improvement E values compared to the untreated soil. The improvement is in the order of 2 and 3 times of magnitude as of the 7 and 28 curing days, respectively.

In order to apply these findings for practical use, the correlation between parameters frequently conducted. The correlations can provide a rapid and straightforward estimation which is useful for verifying in situ and laboratory results, also can be used for preliminary design.

3.4. Dry-Wet Cycles of Unconfined Compressive Strength

The effect of dry-wet cycles test on the UCS values show that all the specimens (untreated and treated soil) initially increased for the dry-stage and dropped significantly in the wet stage for each D-W cycle as shown in **Fig. 5**. The D-W cycles test generally show a higher in the UCS values of cement-treated soil mixed with binder mineral compared to untreated soil. An increase in D-W cycles induces a gradual weakness in strength of all soil specimens.

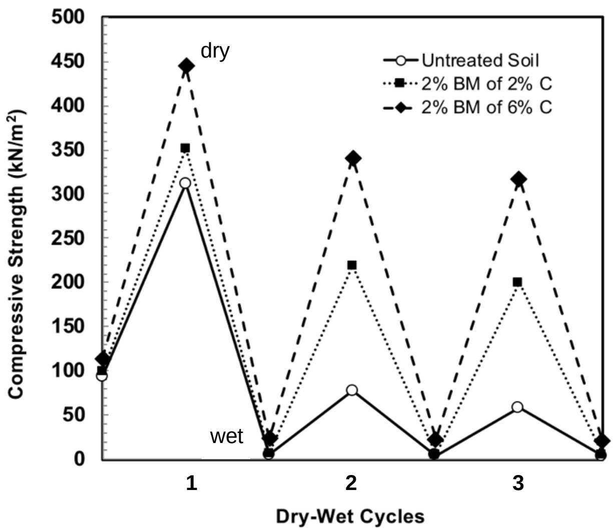


Fig. 5. UCS of 2% binder mineral of 2 and 6% cement content subjected to dry-wet cycles

It is showed in **Fig. 6(a)** that the percentage increase in UCS value of 6% cement content specimen is higher than the corresponding 4% and followed by 2% cement-treated soil with binder mineral additive (2% of cement content). The UCS value of 6% cement-treated soil specimen subjected to 1st dry cycles is approximately 50% higher than the corresponding UCS value of untreated soil in the dry stage. The increase of UCS values also found for the 4 and 2% cement-treated soil with an increase of 30 and 15%, respectively. Similar behaviour was reported by previous study (Miller and Zaman 2000; Solanki and Zaman 2002). However, the subsequent dry cycles (2nd and 3rd cycle stage) showed the decreasing in the UCS value. The UCS value for 6% of cement content decreased by 22 and 30% for 2nd and 3rd dry cycles. The higher reduction of UCS value observed for 2% cement-treated soil which is about 35 and 40% for the 2nd and 3rd dry

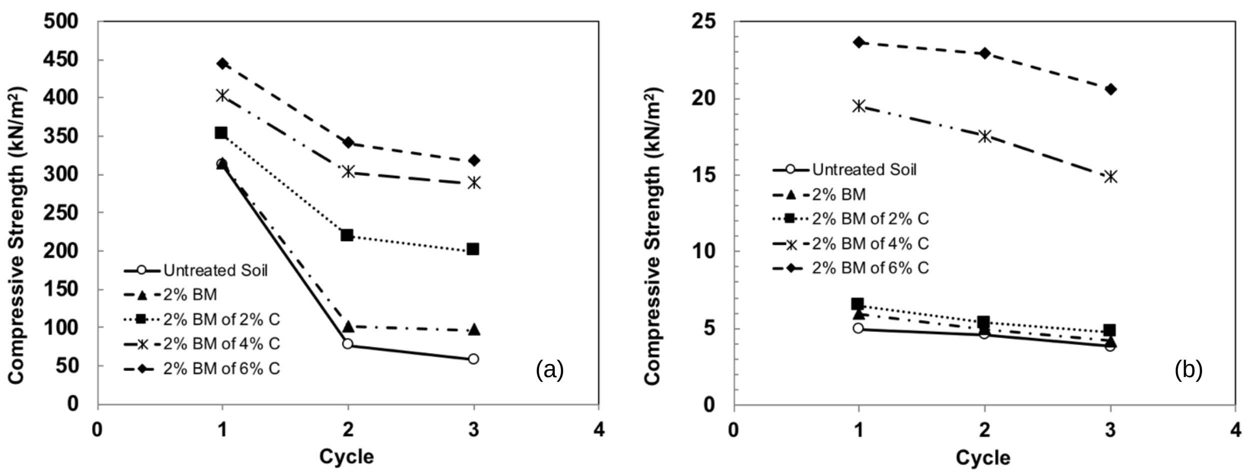


Fig. 6. Variations of UCS value subjected to dry-wet cycles: (a) Variations of UCS value in dry cycle and (b) Variation of UCS value in wet cycle

cycles. The drying process forms the cement-treated soil samples shrinking due to the reduction of the pore volumes and tension developed. Subsequently, it causes tension and the surface cracks on the sample (Tang et al. 2011). Cement and binder mineral enhance not only the strength development but also the durability to the strength due to the strength mainly governed by the pozzolanic reaction.

Similar behaviour observed for wet cycle as shown in **Fig. 6(b)**. The change of UCS value by increasing the number of wet cycles showed that the strength of cement-treated soil and untreated soil reduced significantly. The UCS of cement content lower than 4% similar behaviour to the untreated soil. It is indicated that the presence of cement in the soil inadequate to improve the soil for wetting cycle. The repulsive forces and the tension and surface crack upon the wetting cycles reduce the strength of the cement-treated soil.

The relationship between $UCS_{initial}$ and $UCS_{(D\text{-}W\ cycles)}$ shown in **Fig. 7**. The strength of any number of cycles ($UCS_{(D\text{-}W)}$) is directly correspond to the $UCS_{initial}$. The relationship between $UCS_{initial}$ and $UCS_{(D\text{-}W)}$ for each cycle are presented in the following **eq. [3], [4] and [5]** of 1, 2 and 3 cycles, respectively. The linear relationship exists for the number of dry-wet cycles of 1, 2 and 3. The relationship could be used for simple/quick approximation of the dry-wet cycle strength of the cement-treated soil with binder mineral additives.

$$UCS_{(D\text{-}W)} = 5.8811\ UCS_{initial} - 237.12 \quad [3]$$

$$UCS_{(D\text{-}W)} = 12.082\ UCS_{initial} - 1035.7 \quad [4]$$

$$UCS_{(D\text{-}W)} = 12.053\ UCS_{initial} - 1054.1 \quad [5]$$

All the specimens tested in this study generally showed an increase in UCS values at the end of the first dry-wet

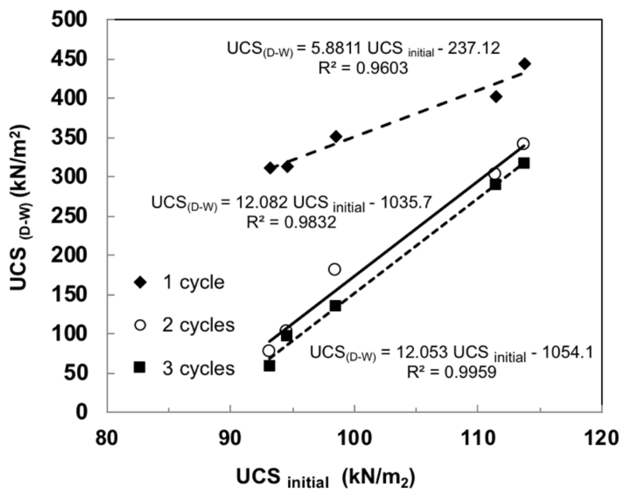


Fig. 7. Relationship between $UCS_{initial}$ and UCS $_{(D\text{-}W\ cycles)}$

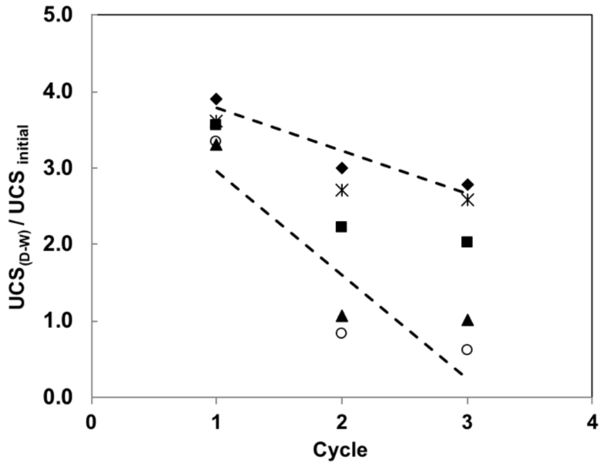


Fig. 8. Relationship between normalized strength and number of cycles

cycle. Even though the cement-treated soil with binder mineral additives shows an improvement of strength, the durability against the dry-wet cycles is considered low as shown in **Fig. 8**. The application of subsequent drying-wetting cycles on both untreated and treated soils, the compressive strength will reduce. The strength of the cement-treated soil with binder mineral additive reduces significantly with the increasing number of dry-wet cycles, especially for low cement content (i.e. 0, 2, and 4% of cement content).

The effect of cement content on the treated soil by increasing the number of dry-wet cycles indicated that the strength of the cement-treated soil significantly decreased. The higher the number of dry-wet cycles, the lower strength was observed. The effectiveness of cement mixed with soil specimens for the higher number of dry-wet cycle indicated insufficient densification and pozzolanic products to maintain the strength of the soil.

4. Conclusions

The present study was conducted to evaluate the effectiveness of binder mineral additive mixed with cement-treated soil. The portland cement was used in the cement-treated soil and compacted at various cement content.

The addition of small amount of cement (2, 4 and 6%) and binder mineral (2% of cement content) and curing time led to significant improvement in UCS and CBR value. The strength and bearing capacity improvement is a result of the stiffening of the soil by effect of the cement hydration. This improvement involves both densification and the pozzolanic reaction of the treated soil.

All the specimens tested in this study generally showed an increase in UCS values at the end of the first dry-wet cycle. Even though the cement-treated soil with binder mineral additives shows an improvement of strength, the durability against the dry-wet cycles is considered medium to low. The strength of the cement-treated soil with binder mineral additive reduces significantly with the increasing number of dry-wet cycles, especially for low cement content (i.e. 0 and 2% of cement content).

In order to apply these study findings for practical use, the correlation between parameters conducted and determine in this study. The correlations can provide a rapid and straightforward estimation which is useful for verifying in situ and laboratory results, also can be used for preliminary design.

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