International Journal of GEOMATE, July, 2017, Vol.13, Issue 35, pp.180 - 186
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: http://dx.doi.org/10.21660/2017.151216

UNDRAINED SHEAR STRENGTH OF LOW DOSAGE CEMENT-SOLIDIFIED DREDGED MARINE SOILS (DMS) FOR RECLAMATION WORKS

Nurul Syakeera Nordin[1] and *Chee-Ming Chan[2]

[1,2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia

*Corresponding Author, Received: 20 Nov. 2016, Revised: 20 Feb. 2017, Accepted: 6 March 2017

ABSTRACT: The disposal of dredged marine soils (DMS) into the ocean or on land are unsatisfactory in managing its large quantity which indicates a high demand on new ocean and land disposal. DMS are classified as contaminated waste that contain of organic matter and heavy metals. Contaminated DMS can harm aquatic organism, animals and human. It must be disposed safely to ensure the contaminants are not released. By reusing the DMS as geomaterial or fill for reclamation works, it will minimize the impact to environment. The treatment techniques towards DMS are an essential and necessary in enhancing its engineering properties and assuring the effectiveness for a long-term solution. This paper presents a preliminary study in solidifying the Kuala Perlis DMS (3.4 *LL*) with lowest dosage of cement (1 – 10 %) at different curing period (3, 7, 14 and 28 days). It shows the undrained shear strength (c_u) value of cement-solidified were increased compare to the raw DMS. The results for cement dosage above 7 % shows a good improvement in c_u value and the strength development were found increased after 3 days of curing. It was explained that the lowest water-cement (*w/c*) ratio tend to have a higher c_u value of the cement-solidified DMS.

Keywords: Dredged Marine Soils, Cement-Solidified, Undrained Shear Strength, Water-Cement Ratio

1. INTRODUCTION

Dredging is a maintenance works of ports and navigation channels [1], [2]. These works are crucial in keeping harbors and waterways navigable, preventing flood of river and restoring the ecosystem of degenerative water bodies [3]. The DMS from dredging works are often disposed by dumped in the sea or stored at on land disposal sites [4]. The disposal of it indicates a high demand on new ocean and land disposal sites [5]. It is consumes considerable time and possesses economical constrains. Furthermore the disposal of the large volume of these unwanted soils always poses significant practical challenges [1], [6]. The presence of contaminants in DMS has created awareness towards the ocean disposal where it may pose a potential threat to water quality and aquatic life. Moreover, the on land disposal sites are getting lesser due to the increasing pressure from urbanization [3].

To minimize the negative effects on environment and to reduce the need for new disposal areas, it is encouraged to utilize the DMS for beneficial uses [1], [3]-[5]. DMS can be reused in sustainable solution as geomaterial for construction and reclamation works if it is treated with suitable treatment techniques [1], [6]. Though, DMS are exhibit with low shear strength, high compressibility and their natural water content are higher than its liquid limit (*LL*) [1], [3]. Solidification technique has been chosen in this study by mixing the DMS with cement. The cement-solidified DMS shows a significant improvement in its mechanical properties similarly to cement-solidified clay [4]. Solidification technique towards DMS will enhance its mechanical properties such as strength, compressibility and permeability. Additionally, it will alter the chemical characteristic by minimizing the rate of contaminant migration from DMS and reducing the rate of heavy metals [5]. The cement-solidified DMS was then can be reused as fill for reclaimed land as shown in Fig.1. Lower dosage of cement are required for stabilized dredged fill compared with traditional cement-treated soils. In land reclamation technology, the reclaimed structure is made up of slurry like cement-stabilized soil and the strength are much lower than traditional cement-treated soil [6]. The strength of treated material is inversely proportional to the *w/c* ratio [4]. Chan [2] emphasized that *w/c* ratio is an important factor to determine the soil's ultimate strength and stiffness.

Numerous studies have attempted to explain the changes in properties of clay soils and DMS as affected by the amount of binder, type of binder and curing time [1], [7]-[10]. Generally, curing time affects the soil's mechanical properties, such as strength. Xiao and Lee [7] highlighted that longer curing time leads to better strength development due to the pozzolanic reaction. Their studies focused on the curing time effect on the hardening behaviour of using cement as the binder. The curing time effect on unconfined compressive strength and compressibility characteristics were examined in their laboratory work. The addition of cement produces the primary and secondary cementatious compound in the soil-cement matrix. These compounds crystallize and harden with time, thus enhancing the strength of the soil cement mixes.

Pakbaz and Alipour [8] traced changes of the unit weight by using 0.6 water-cement (*w/c*) ratio at 7, 14, and 28 days of curing time. It shows the unit weight increased with increasing cement content and curing time. The samples also showed shrinkage at higher amount of cement and curing time. Furthermore, the authors highlighted that the specific gravity values were slightly increased after curing. Du et al [10] identified that the increase of cement content and curing time would be quite effective in enhancing the strength and decreasing the water content, when cement was used to stabilize a zinc-contaminated kaolin.

Raftari et al [9] highlighted the majority of strength in kaolin slurry increased in several weeks after treatment with cement. It is because of the process of hydration and pozzolanic reactions. It is clearly shown that curing time affects the treated soil properties as supported by previous studies reporting that pozzolanic activity begins upon 28 days of curing [1], [11], [12]. Raftari et al [9] also mentioned the water content of treated soil decreased because some existing water content participates in the cement hydration process.

Generally, the properties of DMS are similar to natural soft clays. Once cement was added to solidify a clay soils, it would strengthen the soil fabric by dissociating the clay particle clusters and bind them at intercluster spaces. The small amount of cement makes the cementitious products inadequate to link up the clay cluster at large intercluster spaces. However some strength increase are foreseeable because some small intercluster spaces can be bound to some degree due to the existence of these cementitious products. When the amount of cement increases, it would further enhance the strength of the interlinkages among clay particle clusters in direct proportion to the amount of cementitious products [6 [13], [14].

The strength of clay soils are contributed by the chemical reaction known as pozzolanic reaction. It involves the combination of silicate materials with cement chemically to form non-water-soluble compound leading to solidification of the soil matrix. Furthermore, the pozzolanic reaction can continue for a long time [15]. The cement-solidified DMS involves the hydration of cement, pozzolanic reaction of clay minerals in the soil as well as interaction between the resulting hydrates and soil particles [3], [5]. Pozzolanic reactions are the derivation of calcium hydroxides ($Ca(OH)_2$) from cement hydration that participate in reactions with clay particles [6], [16].

The pozzolanic reaction are [5];

$$Ca^{2+} + OH^{-} + SiO_2 \rightarrow C\text{-}S\text{-}H \quad (1)$$

$$Ca^{2+} + OH^{-} + Al_2O_3 \rightarrow C\text{-}A\text{-}H \quad (2)$$

Where;

SiO_2: active silicate dissociated from clay particles

Al_2O_3: active aluminate dissociated from clay particles

C-S-H: strength-enhancing products calcium silicate hydrate

C-A-H: strength-enhancing products calcium aluminate hydrate

Pozzolanic reactions need a strong base environment (pH > 11). SiO_2 and Al_2O_3 are weak acids, hence they are able to considerably dissolve in strong base [6]. However, the strong base are possible to be built up when the amount of cement is too small and therefore mainly hydration reaction products are produced. When the cement's amount increase, part of the active SiO_2 and Al_2O_3 begins to participate in pozzolanic reaction. Nonetheless, the major hydrates formed of *C-S-H* and *C-A-H* produced by pozzolanic reaction is not in direct proportion to the amount of cement. When the amount of cement exceed a threshold, the strong base environment is already built up by previous hydration products. The hydration and pozzolanic reaction can proceed simultaneously and reinforce each other [6]. Rahman et al [17] explained that the *w/c* ratio can also affect the rate of hardening related to the hydration and pozzolanic reactions.

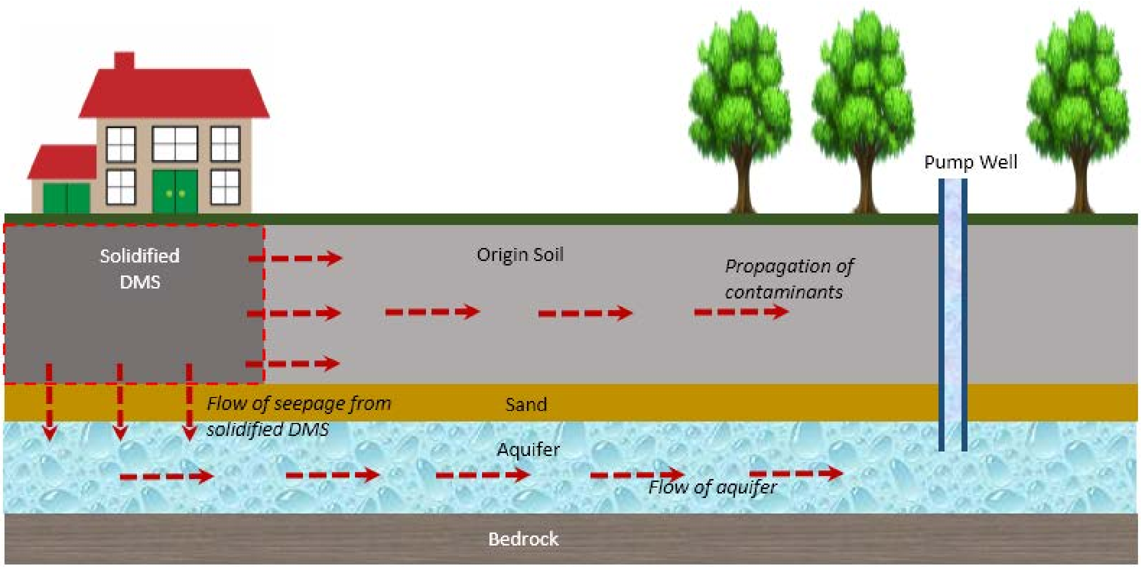

Fig.1 The scenario of cement-solidified DMS as fill material for reclaimed land with the illustration of seepage's flow and contaminant's propagation

2. EXPERIMENTAL WORK

2.1 Materials

The studied materials was dredged from Kuala Perlis, Kedah of Peninsular Malaysia in year 2016. The properties results of the dredged materials are reported in Table 1. The natural water content is about 240.74 % (3.4 *LL*), dried in an oven at 100 ºC (BS 1377-2:1990:3.2). The particle density value of dredged material is 2.36 Mg/m^3, measured using a small pyknometer method (BS 1377-2:1990:8.3). The liquid limit value is 71.70 % by using a cone penetrometer method (BS 1377-2:1990:4.3). The plastic limit and plastic index value for dredged material are 40.06 % and 31.64 %, respectively (BS 1377-2:1990:5). The dredged material was classified in high plasticity silt, *MH* for its soil type (Unified Soil Classification System).

Table 1 Properties of dredged marine soils

Soil type	High plasticity silt, *MH*
Natural water content, w_{nat} (%)	240.74
Specific gravity, G_s (Mg/m^3)	2.36
Liquid limit, *LL* (%)	71.70
Plastic limit, *PL* (%)	40.06
Plastic index, *PI* (%)	31.64

2.2 Preparation of test specimens

Distilled water was added to the DMS to achieve the consistency of 3.4 *LL* for each sample to achieve the same as natural water content of the DMS. Cement was added to the DMS at a lowest dosage of 1 – 10 %, corresponding to the *w/c* ratio as shown in Table 2. DMS and cement was thoroughly mixed by using kitchen mixer at a lower speed. The mixture was then transferred into a rectangular airtight container (see Fig.2) and cured for 3, 7, 14 and 28 days before a laboratory vane shear test were performed.

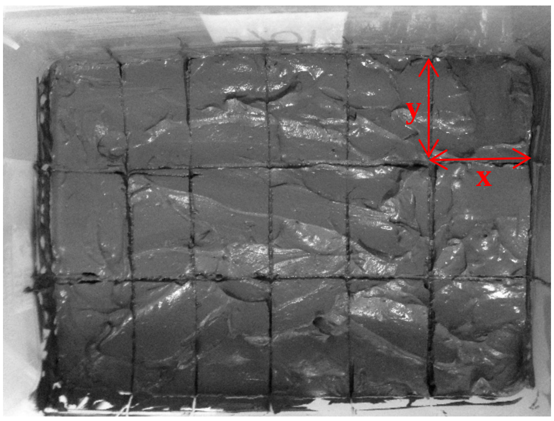

Fig.2 Cement-solidified DMS specimen

Table 2 Specimen list and mix ratio

Specimen	Natural Water Content %	Mix Proportions				Cement Dosage (%)	*w/c*
		Wet Soil (g)	Dry Soil (g)	Water, W (g)	Cement, C (g)		
1C					5.87	1	240.7
2C					11.74	2	120.4
3C					17.61	3	80.2
4C					23.48	4	60.2
5C	240.74	2000.00	586.96	1413.04	29.35	5	48.1
6C					35.22	6	40.1
7C					41.09	7	34.4
8C					46.96	8	30.1
9C					52.83	9	26.7
10C					58.70	10	24.1

2.3 Vane shear test

Laboratory vane shear test was performed towards the cement-solidified DMS to determine the undrained shear strength value. This experiment is one of the more practical ways because the others strength's experiment seems unsuitable to be applied to the slurry like condition of the DMS and the lowest dosage of cement added makes the specimen in a fragile condition. The diameter and height of the blade used were 12.7 mm each (BS 1377-7:1990:3).

3. RESULTS AND DISCUSSIONS

3.1 Undrained shear strength, c_u

The undrained shear strength was obtained by laboratory vane shear test. Fig.3 presents the results obtained from the preliminary analysis of c_u at a lowest dosage of cement. It shows the c_u value of the DMS were proportionated to the curing period. At dosage of 1 – 6 %, the rate of c_u increment are gradually decreased after 14 days of curing. While, the c_u are increases rapidly up to 14 days of curing for dosage 7 – 10 %. It was believed that the c_u will continuously increase beyond the 28 days of curing. It is because extended curing time is required to induce cementation of soil [2]. Kang et al [1] clarifies the pozzolanic reaction will begin upon 28 days of curing where indirectly will producing the cementing products in cement-solidifed DMS.

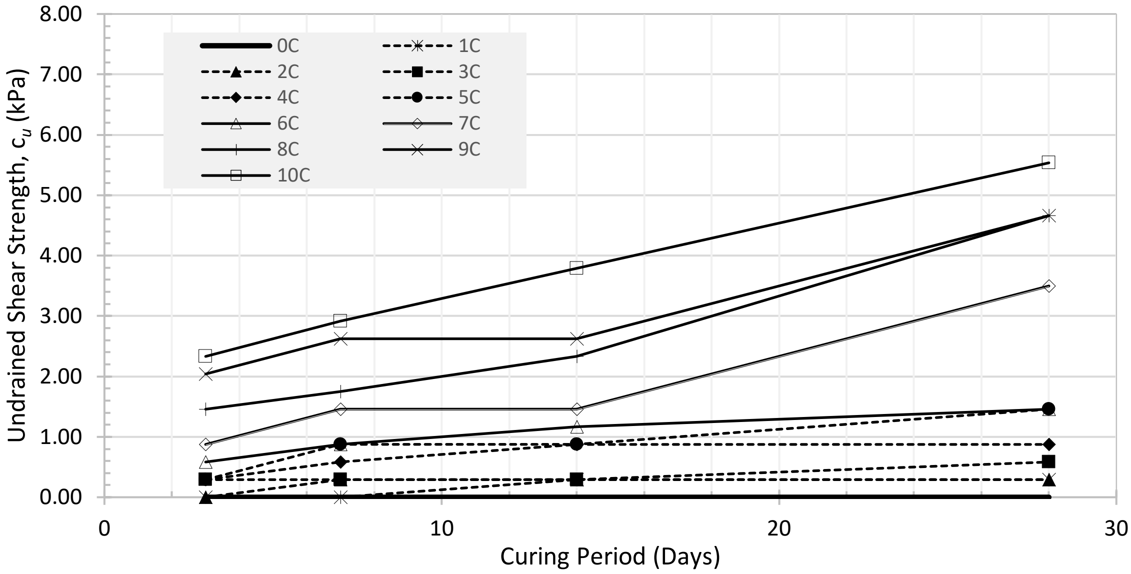

Fig.3 Undrained shear strength at different curing period

3.2 Relationship c_u – *w/c*

The relationship of c_u and *w/c* for the preliminary study are presented in Fig.4. These two factors describes a good correlation between the c_u and *w/c* value. It shows the high value of *w/c* tend to have the lowest c_u and it verifies the *w/c* factor are strongly affecting the c_u of cement-solidified DMS. Furthermore it shows the prolonged curing of cement-solidified DMS results in continuous increasing of c_u. Fig.5 – Fig.8 shows the gradient value of the active and less active zones for each curing day. It shows the prolonged curing will increase the gradient value for each zone. Those values explained the strength of DMS were strongly affected by the *w/c* ratio and prolonged curing of the specimens. A future investigation in using the different *w/c* ratio are recommended in which to examine the effects towards c_u value.

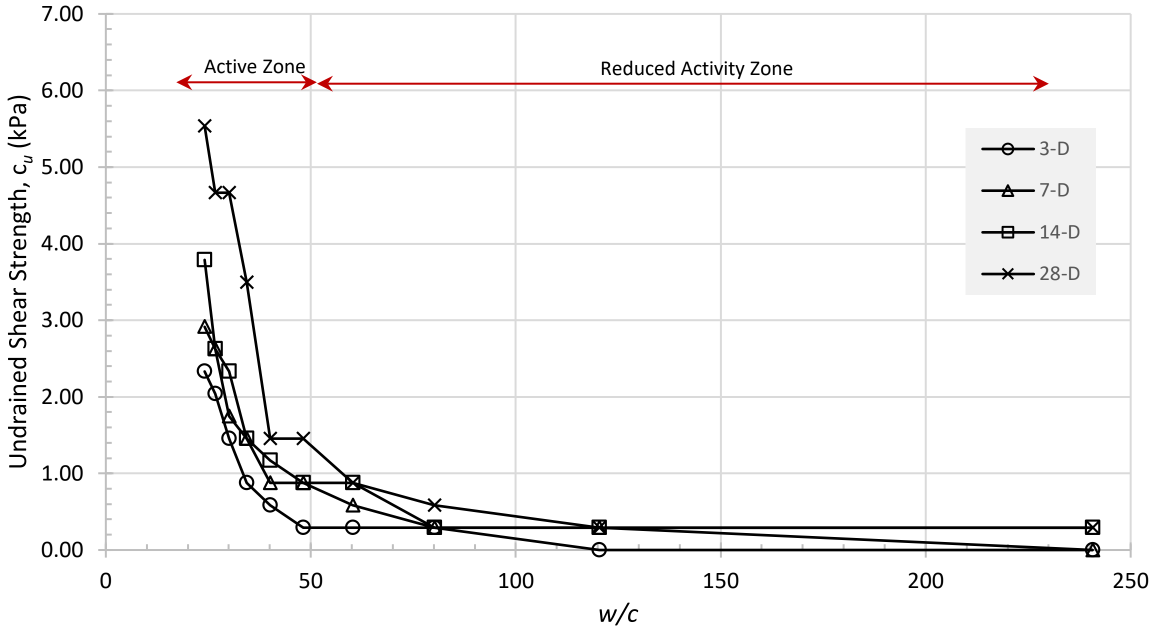

Fig.4 Relationship between undrained shear strength and water-cement ratio

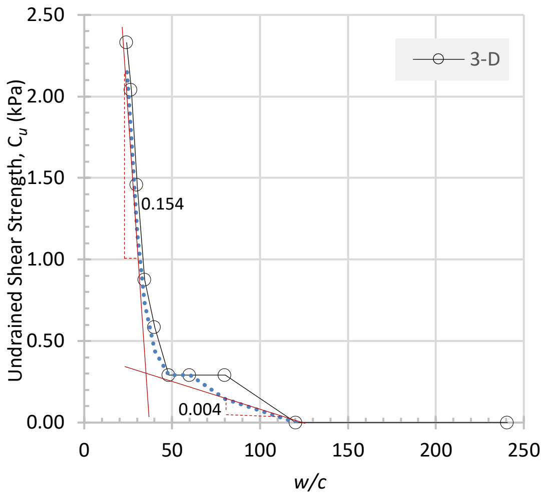

Fig.5 Relationship between undrained shear strength and water-cement ratio at 3-D of curing

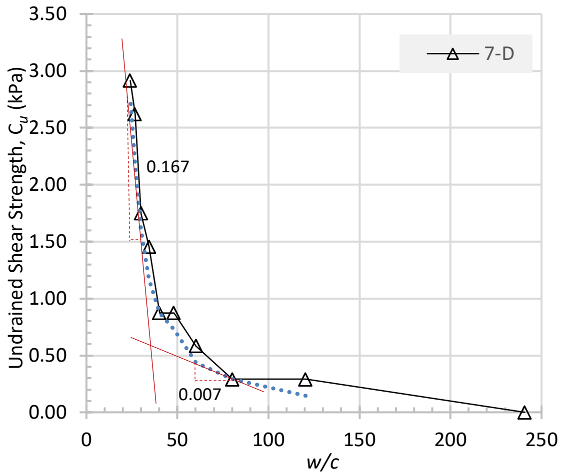

Fig.6 Relationship between undrained shear strength and water-cement ratio at 7-D of curing

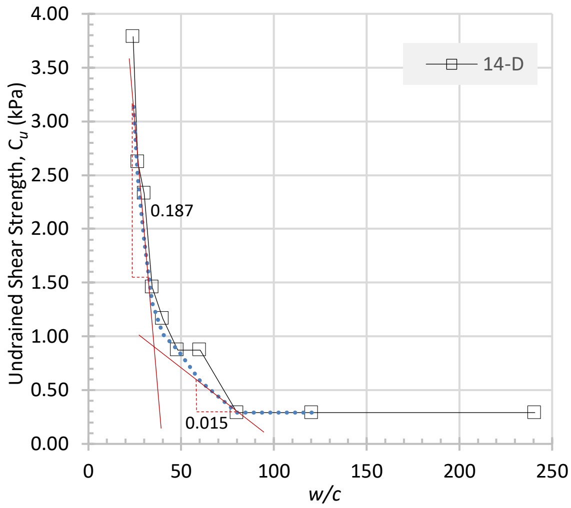

Fig.7 Relationship between undrained shear strength and water-cement ratio at 14-D of curing

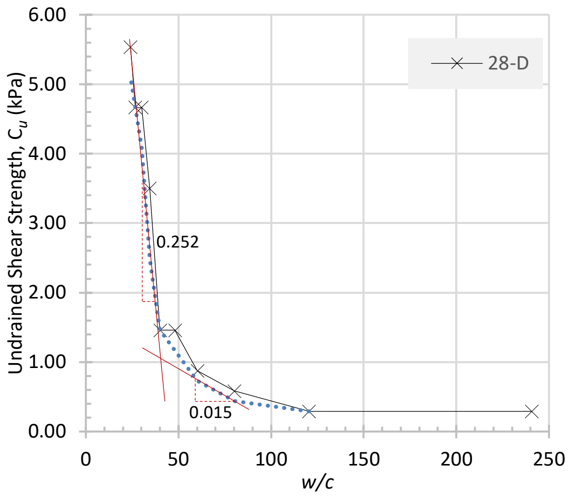

Fig.8 Relationship between undrained shear strength and water-cement ratio at 28-D of curing

4. CONCLUSIONS

The most obvious finding to emerge from this preliminary study is that the c_u value of cement-solidified DMS were induced by the lower *w/c* and continuous curing time. Most of the c_u increment is developed in 14 days of curing time and the great increment in c_u value showed for cement dosage above 7 %. The prolonged curing showing an increment value of c_u. It was evidently supported by previous study where the pozzolanic activity will begin upon 28 days of curing in producing the cementing products of DMS. The *w/c* ratio is a prime parameter in analysis the properties of DMS. The higher strength of DMS will be induced by the lower value of *w/c* with the enhancement of the cementation bond strength. Further investigation and experimentation in solidifying 3.4 *LL* DMS with the lowest *w/c* ratio is strongly recommended.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Centre for Graduate Studies, Universiti Tun Hussein Onn Malaysia in providing a fund to produce this research paper.

6. REFERENCES

[1] Kang, G., Tsuchida, T., & Athapaththu, A.M.R.G. Engineering Behaviour of Cement-Treated Marine Dredged Clay during Early and Later Stages of Curing. Engineering Geology, Vol. 209, 2016, pp.163-174.

[2] Chan, C.M. Strength Improvement Characteristics of Cement-Solidified Dredged Marine Clay with Relation to Water-Cement Ratio. International Journal of GEOMATE, Vol. 11, No. 27, 2016, pp.2734-2740.

[3] Zhu, W., Zhang, C.L., & Chiu, A.C.F. Soil-Water Transfer Mechanism for Solidified Dredged Materials. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 133, No. 5, 2007, pp.588-598.

[4] Rekik, B., & Boutouoil, M. Geotechnical Properties of Dredged Marine Sediments Treated at High Water/Cement Ratio. Geo.Mar, Vol. 29, 2009, pp.171-179.

[5] Chiu, C.F., Zhu, W., & Zhang, C.L. Yielding and Shear Behaviour of Cement-Treated Dredged Materials. Engineering Geology, Vol. 103, 2008, pp.1-12.

[6] Zhang, R.J., Santoso, A.M., Tan, T.S., & Phoon, K.K. Strength of High Water-Content Marine Clay Stabilized by Low Amount of Cement. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 139, No. 12, 2013, pp.2170-2181.

[7] Xiao, H.W., & Lee, F.H. Curing Time Effect on Behavior of Cement Treated Marine Clay. World Academy of Science, Engineering and Technology, Vol. 43, 2008, pp.71-78.

[8] Pakbaz, M.S., & Alipour, R. Influence of Cement Addition on The Geotechnical Properties of An Iranian Clay. Applied Clay Science, Vol. 67-68, 2012, pp.1-4.

[9] Raftari, M., A. Rashid, A.S., Kassim, K.A., & Moayedi, H. Evaluation of Kaolin Slurry Properties Treated with Cement. Measurement, Vol. 50, 2014, pp.222-228.

[10] Du, Y.J., Jiang, N.J., Liu, S.Y., Jin, F., Singh, D.N., & Puppala, A.J. Engineering Properties and Microstructural Characteristics of Cement-Stabilized Zinc-Contaminated Kaolin. Canadian Geotechnical Journal, Vol. 51, 2014, pp.289-302.

[11] Cheriaf, M., Rocha, C.J., & Pera, J. Pozzolanic Properties of Pulverized Coal Combustion Bottom Ash. Cem. Concr. Res. Vol. 29, pp.1387-1391.
[12] Kim, Y.T., & Do, T.H. Effect of Bttom Ash Particle Size on Development in Composite Geomaterial. Eng. Geol. Vol. 139-140, pp.85-91.
[13] Horpibulsuk, S., Miura, N., & Nagaraj, T.S. Assessment of Strength Development in Cement-Admixed High Water Content Clays with Abrams' Law as A Basis. Geotechnique, Vol. 53, No. 4, 2003, pp.439-444.
[14] Kamruzzaman, A.H.M., Chew, S.H., & Lee, F.H. Structuration and Destructuration Behaviour of Cement-Treated Singapore Marine Clay. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 135, No. 4, 2009, pp.573-589.
[15] Hino, T., Jia, R., Sueyoshi, S., & Harianto, T. Effect of Environment Change on The Strength of Cement/Lime Treated Clays. Front. Struct, Civ. Eng., Vol. 6, No. 2, 2012, pp.153-165.
[16] Chew, S.H., Kamruzzaman. A.H.M., & Lee, F.H. Physico-chemical and Engineering Behaviour of Cement Treated Clay. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, No. 7, 2004, pp.696-706.
[17] Rahman, M.M., Siddique, A., & Uddin, M.K. Clay-Water/Cement Ratio is the Prime Parameter for Fine Grained Soil Improvement at High Water Content. DUET Journal, Vol. 1, No. 3, 2013, pp.1-11.