Journal of Science and Technology, Vol. 10 No. 4 (2018) p. 13-20

Compressibility and Permeability of Solidified Dredged Marine Soils (DMS) with the Addition of Cement and/or Waste Granular Materials (WGM)

Rosman, M. Z., Chan. C-M.* and Anuar, N. M.

Civil Engineering Technology Department, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia,
84600, Pagoh, Johor, Malaysia.

Received 15 September 2018; accepted 1 December 2018; available online 30 December 2018

DOI: https://10.30880/jst.2018.10.04.003

Abstract: Dredged marine soils that obtained from dredging work were characterize as geo-waste, which is prone to be dumped rather than to be reused. This type of soil is high in compressibility and low in load bearing capacity. The engineering properties of this soft soil can be improve via soil solidification method. Cement is the common hydraulic binder used in soil solidification, were found to generate the emission of greenhouse gasses (GHG), particularly carbon dioxide (CO2) which also had affected the earth's atmosphere. Therefore, there has been an increasing interest in using alternate pozzolanic materials such as waste granular materials (WGM) to fully or partially substituted the use of cement in soil solidification. WGM such as coal bottom ash (BA) and palm oil clinker (POC) were opted due to its pozzolanic properties. Prior to the planning of reclamation work using DMS admixed with conventional and/or alternate pozzolanic materials, the consolidation characteristics of the admixed materials must be acknowledged. Hence, the present study will examine the amount of settlement and coefficient of permeability (k) of DMS treated with cement and/or WGM in laboratory-scale experiments. Samples were prepared in various proportion in order to examine the individual effect of the cement and/or alternate pozzolanic materials on compressibility and permeability. For cement-admixed DMS, sample with 20 % of cement have significantly reduced the settlement than untreated and 10 % cemented DMS. For WGM-admixed DMS, the initial void ratio is low as compared to the untreated DMS due to the rearrangement of soil particles, which is densely packed. For cement-WGM-admixed DMS, samples of 15C50BA and 15C50POC displayed significant settlement reduction than 10C100BA, 10C100POC and untreated samples.

Keyword: Compressibility; Permeability; Dredged Marine Soil; Cement; Waste Granular Materials.

1. Introduction

In order to clear and maintain the ship's navigation channel, dredged marine soils (DMS) are required to be excavated out along the waterway. DMS is characterized as geo-waste which is prone to be dumped rather than to be reused [1]. This type of soil is high in compressibility and low in load bearing capacity. Therefore, if certain structure is imposed on top of this weak soil, it would incur the chance of extreme consolidation settlement.

Soil improvement method such as soil solidification is able to enhance the engineering properties of this soft soil. Cement is the common hydraulic binder used in soil solidification. Back in the year of 1970's, it was extensively used for construction and soil improvement works [2]. The inclusion of cement in soil will cause cation exchange, flocculation-agglomeration, pozzolanic and hydration reactions [3]. According to [4], soil-cement reaction can be sub-divided into two parts, namely primary and secondary reactions. Primary reaction takes place when clay is added into a mixture of water and cement. During this stage, the cement-hydration products reacted and formed a hardened soil-skeleton. The secondary reaction or also known as pozzolanic reaction is resulted from the secondary-cementation products. Along time, the soil will become hard and the strength will further improved.

However, high production of cement had caused the emission of greenhouse gasses (GHG), particularly carbon dioxide (CO2) which also had affected the earth's atmosphere. In addition, approximately 5-8 % of global man-made CO_2 discharges were originated from the cement manufacturer [5]-[8]. Therefore, there has been an increasing interest in using alternate pozzolanic materials to fully

*Corresponding author: chan@uthm.edu.my

e-ISSN: 2600-7924/penerbit.uthm.edu.my/ojs/index.php/jst

or partially substitute the use of cement in soil improvement work. Pozzolanic materials possess low cementitious properties that will chemically reacts in the presence of water. Recent evidences suggested that pozzolanic materials with high value of silica dioxide (SiO_2) and alumina oxide (Al_2O_3) would further promote the pozzolanic reaction [7], [9], [10]. There are large volumes of waste granular materials (WGM) such as coal bottom ash (BA) and palm oil clinker (POC) that contain pozzolanic properties. BA is a byproduct of coal combustion which is used to generate steam and then converted into electricity in power generation plant. As for POC, it is a biomass byproduct of incinerated palm fiber husk and shell which is also used to generate power in the palm oil mill. Both of these wastes or byproducts have low commercial values. Hence, by acknowledging the pozzolanic nature of BA and POC, it is possible to beneficially reuse these materials in soil improvement work specifically to be admixed in DMS.

Prior to the planning of reclamation work using DMS admixed with conventional and/or alternate pozzolanic materials, the consolidation characteristics of the admixed materials must be acknowledged. The rate and magnitude of settlement and its permeability are the significant factors of consolidation settlement [11]-[13]. Hence, to verify these findings, the present study will examine the amount of settlement and coefficient of permeability (k) of DMS treated with cement and/or WGM in laboratory-scale experiments. Samples were prepared in various proportion in order to examine the individual effect of the cement and/or alternate pozzolanic materials on compressibility and permeability. The value of k was determined by using the relationship of coefficient of consolidation (c_v), coefficient of volume compressibility (m_v) and unit weight of water (γ_w) as expressed in equation (1).

$$k = c_v \times m_v \times \gamma_w \quad (1)$$

2. Materials and Methods

The materials used in this study were DMS, BA and POC. Ordinary Portland cement (C) was also used as comparison between the conventional and alternate binders effect on DMS. DMS were retrieved from Kuala Muda waterways in Kedah district, Malaysia. The sample was taken from a depth of 8-10 m from the sea level by using a trailing suction hopper dredger. The raw samples were secured in plastic bags and stored inside large air-tight containers to avoid moisture loss.

BA was collected from Tanjung Bin Power Plant in Pontian, Johor. It has a porous, glassy and dark appearances. As for POC, it was collected from Keck Seng (M) Sdn. Bhd. in Masai, Johor. POC was obtained in the form of large chunks with rough and porous surfaces. As displayed in Fig. 1 and Fig. 2, both of these materials were crushed and sieved passing 2 mm to keep it uniform. Then, the materials were oven-dried at 105°C for 24 hours to ensure no moisture intact prior to mixing. In Fig. 3, particle size distribution of DMS, BA and POC were shown. It has been suggested that BA tend to show brittleness attributes [14]. For that reason, DMS is appeared to be finer than BA and POC accordingly.

Fig. 1 Coal bottom ash (BA).

Fig. 2 Palm oil clinker (POC).

Summaries of physical and chemical properties of the materials used in the present study were tabulated in Table 1 and Table 2 respectively.

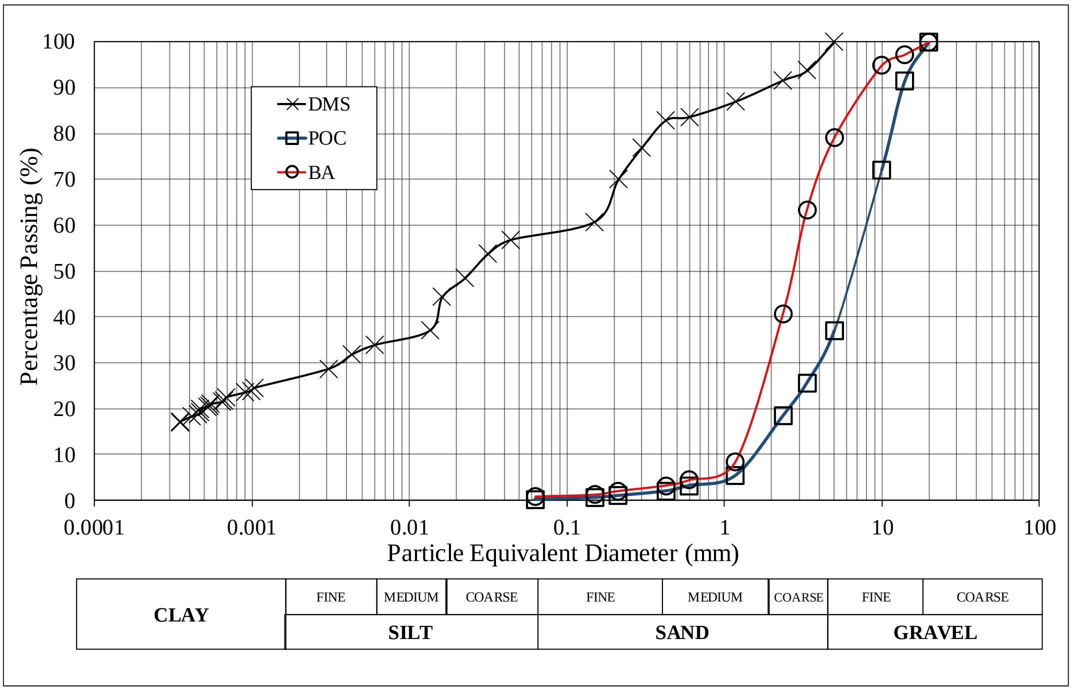

Fig. 3 Particle size distribution of the materials used

Table 1 Physical Properties of DMS, BA and POC

Properties	DMS	BA	POC
Natural water content, WC (%)	91.96	-	-
Liquid limit, LL (%)	47.70	-	-
Plastic limit, PL (%)	31.50	-	-
Plasticity index, PI (%)	16.20	-	-
Specific gravity, SG	2.57	2.56	2.23
Soil classification	ML	GP	SP

Table 2 Chemical Properties of DMS, BA and POC

Oxides (%)	BA	POC	C
Silicon Oxide (SiO_2)	48.70	80.8	24.50
Aluminum Oxide (Al_2O_3)	26.50	4.50	9.42
Calcium Oxide (CaO)	8.80	2.30	54.20
Iron Oxide (Fe_2O_3)	8.50	5.20	5.20
Titanium Oxide (TiO_2)	1.95	0.17	0.69
Magnesium Oxide (MgO)	1.85	1.34	1.40
Potassium Oxide (K_2O)	1.10	3.66	0.98
Others	2.05	0.90	2.30
Classes	F	F	C

Clearly from these tables, DMS exhibited high water content which exceed its liquid limit. In addition, DMS was classified as low plasticity silt (ML), whereas BA and POC were classified as particles in range of gravel-sand based on example of a standard in [15]. As from the chemical properties test results, it can be seen that C possess higher value of calcium oxide (CaO) than BA and POC. CaO or lime contributes to the primary reaction when it reacts with water. By referring to a standard [16], the total of $SiO_2+Al_2O_3+Fe_2O_3$ > 50% or CaO > 10 % is considered as Class C (cementitious) type and $SiO_2+Al_2O_3+Fe_2O_3$ > 70% is considered as Class F (pozzolanic) type. It is apparent that C is highly cementitious as compared to BA and POC. As mentioned in the prior studies, higher values of silicon oxide (SiO_2) and aluminum oxide (Al_2O_3) mainly promote the secondary reaction or what known as pozzolanic reaction [10], [17]-[19]. These attributes can be found in the BA and POC that are used in the study.

The soil samples were treated with 10 and 20% of cements by dry weight of soil. Many studies have proven that cement content at minimum of 10% had improved the engineering properties of DMS [20], [21]. Moreover, previous researchers have reported that 50-100% of BA and POC have resulted with significant gain of strength and stiffness which was influenced by the inter-particle bonding and pozzolanic reaction of these granular materials [19], [22], [23]. Hence, 50 and 150% of BA and POC by dry weight of soil were also used in this study. Proportion of materials in mixtures are shown in Table 3. By using a kitchen mixer, the mixture was mixed thoroughly and then compacted in the standard oedometer ring. According to [24], the curing period of 7 days have significantly improved the shear strength and shear resistance of the cement or WGM treated DMS. Thus, the soil samples were left to cure in room temperature for 7 days prior to testing. After that, the soil samples would undergo incremental stress of 12.5, 25, 50, 100, 200, 400 and 800 kPa correspondingly.

Table 3 Mix Design of Samples

Sample	Cement (%)	BA (%)	POC (%)
Untreated	-	-	-
10C	10	-	-
20C	20	-	-
50BA	-	50	-
150BA	-	150	-
50POC	-	-	50
150POC	-	-	150
10C100BA	10	100	-
15C50BA	15	50	-
10C100POC	10	-	100
15C50POC	15	-	50

3. Results and Discussions

The results of compressibility and permeability for the different proportioned samples are presented in Fig. 4, Fig. 5 and Fig. 6. For cemented soil samples in Fig. 4, 20 % of cement in DMS shows lower settlement than 10 % of cemented DMS. It is obvious that the cement hardening effect of sample 20C have reduced the settlement effectively. But, high amount of cement in DMS has influenced the coefficient of permeability (k) of the soil sample. Interestingly, for those samples with higher cement content (sample 20C), it displays lower k-value than 10C and untreated samples. The present findings are consistent with those of other studies and suggest that the k-value was influenced by the inter-aggregate pores [25]. As the cementation products start to fill in the inter-aggregate pores, it will gradually reduce the permeability of the soils. In addition, the size of the soil's pore decreased accordingly to the increasing cement content. Hence, it is plausible that the reduction of k-value of cemented soil is related with the reduction of void ratio which is due to the soil's compressibility. This view is also supported by [26] who concluded that the decreasing k-value was influenced by the increasing effective vertical stress (σ'v) and decreasing void ratio (e). Noticed that there were no significant differences between 10C and untreated samples in term of compressibility and permeability. It seems possible that these results are due to the low amount of cement in highly saturated soil. Soft clay with high water content is full with cluster particles of clay which surrounded by inter-cluster spaces. By adding cement in clay, it will bind the inter-cluster spaces together and strengthen the soil fabric. However, due to the low amount of cement, the cement products are unable to bind the larger inter-cluster space. Thus, weaken the bond of the soil-cement. This also accords with other researchers which found that low cemented soil with high water content have reduced the effect of cementation bond [27]-[29].

In Fig. 5, it is apparent that WGM-admixed DMS have low initial void ratio as compared to the untreated DMS. Reference [30] found that as the percentage of WGM increased, the initial void ratio decreased. But, when larger σ'v was applied on the samples admixed with 150% of WGM, the void ratio remained higher than the untreated and 50% of WGM admixed samples. It can thus be suggested that as stress applied, the soil and WGM particles tend to rearrange into dense pack of particles which resulted to the almost constant void ratio. According to [31], due to the irregular shape and rough surface of WGM, it provides inter-particle bond to the contact surfaces, thus gives adequate soil-skeleton structure. Referring to [19], it also stated that the higher the interlock degree in soil, the greater its shear resistance. In term of permeability, untreated and 50% of WGM-admixed DMS have resulted with high k-value than 150% of WGM-admixed DMS. This shows that the high amount and various particle sizes of WGM in DMS

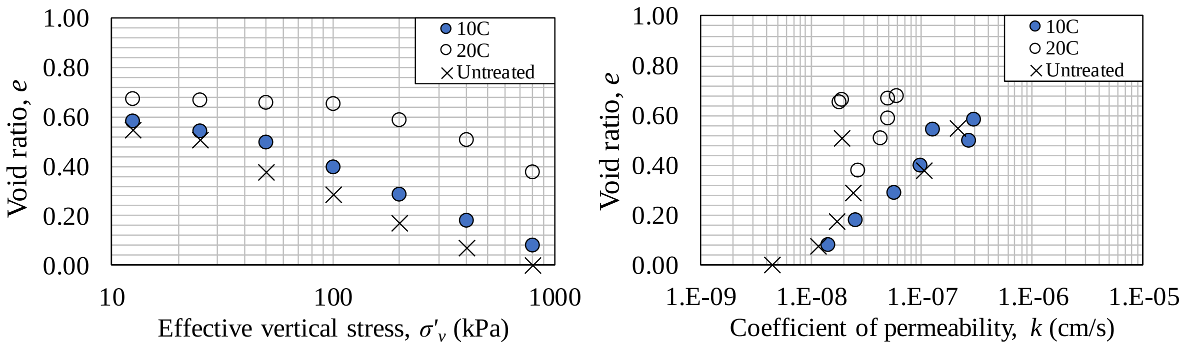

Fig. 4 Compressibility (left) and permeability (right) graphs of cement-admixed DMS sample.

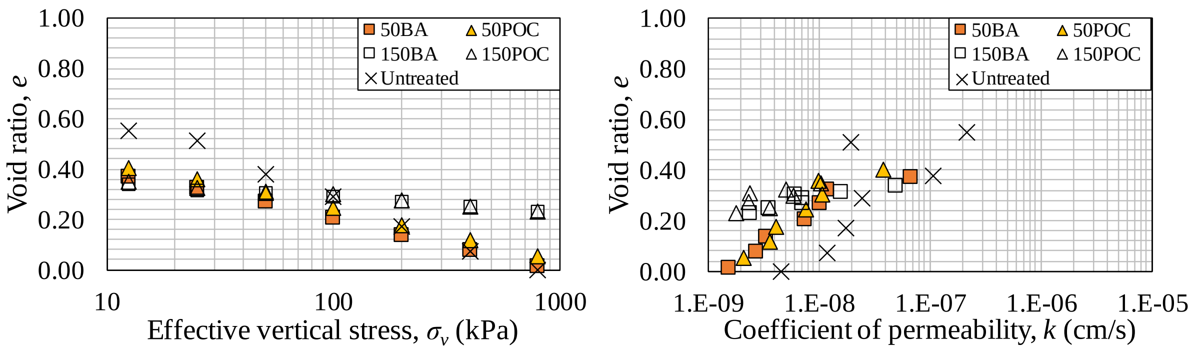

Fig. 5 Compressibility (left) and permeability (right) graphs of WGM-admixed DMS sample.

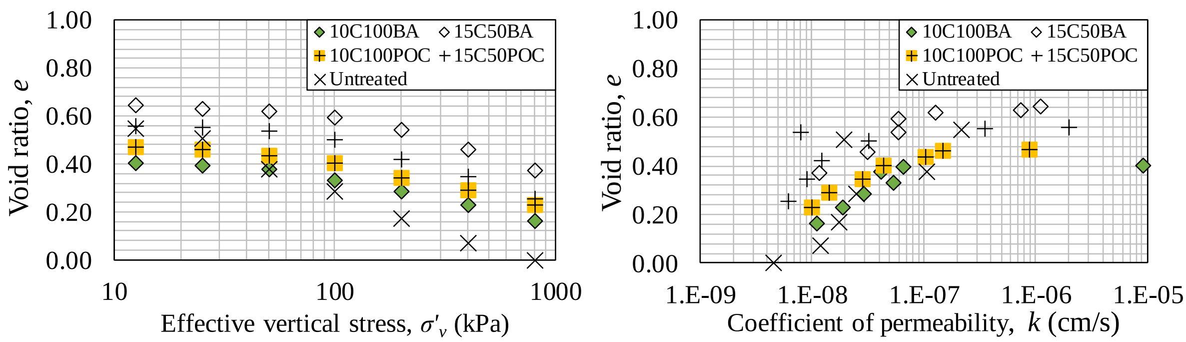

Fig. 6 Compressibility (left) and permeability (right) graphs of cement-WGM-admixed DMS sample.

have affected the permeability of the soil samples. The soil fabric is densely packed and possess smaller range of void ratio which can be clearly seen in sample of 150% WGM. As stated by [32], soil with k-value of 10-8-10-9 cm/s is categorized as impermeable or impervious clay. Less permeable clay tends to surround WGM particles and restrict the drainage path, thus slower down the dissipation of water during consolidation. This idea further supports the example of a master's thesis in [33] which showed that the impermeable clay particles had sealed the drainage path in granular-admixed soil, thus resulted with low permeability.

From the previous results of cemented and WGM-admixed DMS, higher contents of cement and WGM have reduced the settlement considerably than untreated DMS. Hence, the highest percentages of 20% cement and 150% of WGM were excluded from the homogeneous samples. The reason for the exclusion is to prevent the homogenous sample from becoming too stiff due to high cement and WGM contents. Samples of 10C100BA and 10C100POC denote the mixture of low cement and high WGM contents, whereas samples of 15C50BA and 15C50POC denote the mixture of high cement and low WGM contents. By referring to Fig. 6, samples of 15C50BA and 15C50POC displayed significant settlement reduction than 10C100BA, 10C100POC and untreated samples. A possible explanation for this might be due to the high cement content which have mainly influenced the formation of soil-skeleton and also improved the soil's compressibility. For the case of samples 10C100BA and 10C100POC, higher percentages of WGM in admixed DMS have resulted with lower initial void ratio at lower axial vertical stress. As the axial vertical stress increased, the void ratio remained higher than untreated DMS. This result is similar to the samples of 150BA and 150POC. Another important finding was that regardless of the percentages of admixture in the homogeneous samples, the k-value was out of the range of 10-8-10-9 cm/s (impermeable clay). It may be that these results are related with the change of the soil fabric. Soil fabric change is a term to describe the arrangement of soil particles [34]. The increase of the k-value may be induced by the additional open fabric, whereas the reduction of k-value may be due to the cementation products that started to fill in the voids [35], [36]. Therefore, both effects of fabric change and development of soil-skeleton structure (due to frictional resistance of granular material and cementation or pozzolanic reaction of cement and WGM) are the contributing factors of the increasing and decreasing value of k.

4. Conclusions and Recommendations

A series of oedometer tests were conducted on DMS which have been admixed with cement and/or WGM at various percentages. This study set out to determine the individual effect of cement and/or WGM admixed DMS in term of compressibility and permeability. Followings are the key findings from this study;

i. For cement-admixed DMS, sample with 20% of cement have significantly reduced the settlement than untreated and 10 % cemented DMS. This is due to formation of cementation product that hardened the soil-skeleton structure. However, the permeability of sample 20C have reduced than untreated and 10C samples. It is suggested that result is related with the reduction of void ratio which is due to the soil's compressibility.
ii. For WGM-admixed DMS, the initial void ratio is low as compared to the untreated DMS due to the rearrangement of soil particles which is densely packed. The reduced settlement of both samples 50WGM and 150WGM were induced by the frictional resistance of WGM. In term of permeability, untreated and 50% of WGM-admixed DMS have resulted with high k-value than 150% of WGM-admixed DMS. Higher amount of WGM (150%) in DMS have resulted a low permeability soil which may be caused by the reduction of void ratio in the soil fabric.
iii. For cement-WGM-admixed DMS, samples of 15C50BA and 15C50POC displayed significant settlement reduction than 10C100BA, 10C100POC and untreated samples. A possible explanation for this might be due to the high cement content which have mainly influenced the formation of soil-skeleton and also improved the soil's compressibility. Regardless of the percentages of admixture in the homogeneous samples, the k-value was out of the range of 10-8-10-9 cm/s which is categorized as impermeable clay. It may be that these results are related with the change of the soil fabric.

However, based on these findings, further research should be done to investigate the microstructure and chemical composition of the cement and/or WGM admixed DMS samples. Pro-longing the curing period also enable researcher to study the behavior of the admixed samples accordance to time. With this further study, the hypothesis on the contributing factors of the soil's compressibility and permeability results can be validate scientifically.

Acknowledgements

The authors are grateful to the assistance extended to us by assistant engineer at Research Centre for Soft Soil (RECESS) in Universiti Tun Hussein Onn Malaysia (UTHM), Johor.

REFERENCES

[1] Jong, S.Y. and Chan, C-M. (2013) The Fundamental Compressibility Characteristics of Solidified Dredged Marine Soil, *Proceeding of 12th International UMT Annual Symposium*, pp. 597-603.

[2] Jaritngam, S. and Swasdi, S. (2006) Improvement for Soft Soil by Soil-Cement Mixing, *Soft Soil Engineering*¸pp. 637-640.

[3] Sherwood, P.T. (1993) Soil Stabilization with Cement and Lime-State of the Art Review, London.

[4] Kitazume, M. and Terashi, M. (2013) The Deep Mixing Method, Taylor & Francis, London.

[5] Scrivener, K.L. (2014) Options for the Future of Cement, *The Indian Concrete Journal*, pp. 11-21.

[6] Ramezanianpour, A.A. (2014) Cement Replacement Materials: Properties, Durability, Sustainability. Springer, London.

[7] Hicks, J. (2012) Utilization of Coal Combustion By-Products and Green Materials for Production of Hydraulic Cement, Industrial Waste. InTech, France.

[8] Huntzinger, D.N. and Eatmon, T.D. (2009) A Life-Cycle Assessment of Portland Cement Manufacturing: Comparing the Traditional Process with Alternative Technologies, *Journal of Cleaner Production*, pp. 668-675.

[9] El-Shinawi, A. and Kramarenko, V. (2015) Assessment of Stabilized Dredged Marine Sediments using Portland Cement for Geotechnical Applications Along Hurghada Coast, Red Sea Egypt, *Asian Journal of Applied Sciences*, Vol. 3, pp. 819-830.

[10] Gullu, H. (2014) Factorial Experimental Approach for Effective Dosage Rate of Stabilizer, *Soils and Foundations*, Vol. 53, No. 3, pp. 462-477.

[11] Elkateb, T. (2017) Stress-Dependent Consolidation Characteristics of Marine Clay in the Northern Arabian Gulf, *Ain Shams Engineering Journal*, pp. 1-9.

[12] Bae, W.S. and Kwon, Y. (2016) Consolidation Settlement Properties of Seashore Landfills for Municipal Solid Wastes in Korea, *Marine Georesources & Geotechnology*, pp.1-44.

[13] Zeng, L-L., Hong, Z-S, Cai, Y-Q and Han, J. (2011) Change of Hydraulic Conductivity During Compression of Undisturbed and Remolded Clays, *Applied Clay Sciences*, Vol. 51, pp. 86-93.

[14] Jorat, M.E., Marto, A., Namazi, E. amd Amin, M.F.M. (2011) Engineering Characteristics of Kaolin Mixed with Various Percentages of Bottom Ash, *Electric Journal of Geotechnical Engineering*, Vol. 16, pp. 841-850.

[15] American Society for Testing and Materials (2011) Unified Soil Classification System, ASTMD2487-11.

[16] American Society for Testing and Materials (2015) Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolanic for Use as a Mineral Admixture in Concrete, ASTM C618-15.

[17] Rahman, M.E., Leblouba, M. and Pakrashi, V. (2014) Improvement of Engineering Properties of Peat with Palm Oil Clinker, *Pertanika Journal of Science & Technology*, Vol. 22, No. 2, pp. 627-636.

[18] Marto, A., Hassan, M.A. and Othman, B.A. (2013) Shear Strength Improvement of Soft Clay Mixed with Tanjung Bin Coal Ash, *APCBEE Procedia of ICESD*, pp. 116-122.

[19] Kim, Y.T. and Do, T.H. (2012) Effect of Bottom Ash Particle Size on Strength Development in Composite Geomaterial, *Engineering Geology*, Vol. 139-140, pp. 85-91.

[20] Pakbaz, M.S. and Alipour, R. (2012) Influence of Cement Addition on the Geotechnical Properties of an Iranian

Clay, *Applied Clay Science*, Vol. 67-68, pp, 1-4.

[21] Bushran L. and Robinson, R.G., (2010) Strength Behaviour of Cement Stabilised Marine Clay Cured Under Stress, *Indian Geotechnical Conference Mumbai*, pp. 601-604.

[22] Ibrahim, H.A. and Razak, H.A. (2016) Effect of Palm Oil Clinker Incorporation on Properties of Pervious Concrete, *Construction Building Materials*, Vol. 115, pp. 70-77.

[23] Kim, Y.T., Lee, C. and Park, H.I. (2011) Experimental Study on Engineering Characteristics of Composite Geomaterial for Recycling Dredged Soil and Bottom Ash, *Marine Georesources and Geotechnology*, Vol. 29, pp. 1-15.

[24] Rosman, M.Z. and Chan, C-M. (2017) The Effect of Binder and Waste Granular Materials (WGM) on the Shear Strength and Shear Resistance of Dredged Marine Soils (DMS), *MATEC Web of Conferences*, Vol. 87, No. 01022, pp. 1-5.

[25] Quang, N.D. and Chai, J.C. (2015) Permeability and of Lime-and Cement–Treated Clayey Soils, *Canadian Geotechnical Journal*, pp. 1-29.

[26] Wang, J-J., Huang, S-Y., Wen, Y-M., Yang, Y. and Liu, M-W. (2016) Experimental Study on Interaction between Compressibility and Permeability of a Crushed Sandstone-Mudstone Particle Mixture¸*Marine Georesources & Geotechnology*, pp. 1-34.

[27] Tsuchida, T. and Tang, Y.X. (2015) Estimatuon of Compressive Strength of Cement-Treated Marine Clays with Different Initial Water Contents, *Soils and Foundations*, Vol. 55, No. 2, pp. 359-374.

[28] Zhang, R., Santoso, A.M., Tan, T.S. and Phoon, K.K. (2013) Mechanical Behaviour and Environmental Impacts of a Test Road Built with Marine Dredged Marine Sediments¸ *Resources, Conservation and Recycling*, Vol. 52, pp. 947-954.

[29] Jongpradist, P., Youwai, S. and Jaturapitakkul, C. (2011) Effective Void Ratio for Assessing the Mechanical Properties of Cement-Clay Admixtures at High Water Content, *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 137, No. 6, pp. 621-627.

[30] Do, T.H. and Tho, T.X. (2011) Particle Size Effect on Shear Properties of of Bottom Ash Added-Geocomposite Soil, *Journal of Civil Engineering and Architecture*, Vol. 5, No. 8, pp. 748-753.

[31] Kanadasan, J., Fauzi, A.F.A., Razak, H.A., Selliah, P., Subramaniam, V. and Yusoff, S. (2015) Easibility Studies of Palm Oil Mill Waste Aggregates for the Construction Industry, *Journal of Materials*, Vol. 8, pp. 6508-6530.

[32] Head, K.H. (1982) Permeability, Shear Strength and Compressibility Tests, ELE International Ltd., Devon.

[33] Kaliannan, S. (2016) Light Solidification of Kuala Perlis Dredged Marine Soil via Admixtures of GGBS-Cement and Sand: 1-D Compressibility Study. Master Thesis, Universiti Tun Hussein Onn Malaysia, Johor.

[34] West, T.R. (2010) Geology Applied to Engineering. Waveland Press Inc, Illnois.

[35] Jha, A.K. and Sivapullaiah, P.V. (2015) Mechanism of Improvement in the Strength and Volume Change Behavior of Lime Stabilized Soil, *Engineering Geology*, Vol. 198, pp. 53-64.

[36] Nalbantoglu, Z. and Tuncer, E.R. (2001) Compressibility and Hydraulic Conductivity of a Chemically Treated Expansive Clay¸ *Canadian Geotechnical Journal*, Vol. 38, pp. 154-160.