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SETTLEMENT REDUCTION OF DREDGED MARINE SOILS (DMS) ADMIXED WITH CEMENT & WASTE GRANULAR MATERIALS (WGM): 1-D COMPRESSIBILITY STUDY

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ABSTRACT: Dredged marine soils (DMS) are considered as geo-waste and commonly disposed far into the sea. Environmental impacts raised from dredging such as turbidity and disturbance of marine ecosystem had increased the social demand to reuse DMS in engineering application. Typically, DMS have low shear strength and low bearing capacity. Hence, the DMS could be strengthened up by soil solidification. In present study, waste granular materials (WGM) such as coal bottom ash (BA) and palm oil clinker (POC) were utilized as additional binder to cement. The DMS were solidified with 3 series of admixtures; namely cement and/or WGM. The factor that influenced the compressibility of the soil sample such as percentages of admixtures were considered. Proportioned samples of 10, 15 and 20 % of cement, and/or 50 and 150 % of WGM of dry weight of DMS were subjected to one-dimensional oedometer test. The test samples were cured for 7 days in room temperature. Results show that cement- and WGM-admixed DMS have reduced the soil's compressibility considerably than the untreated sample. As expected, the cemented soil had significantly reduced the settlement better than WGM-admixed soil. Hence, homogeneous samples of 15C50BA and 10C100POC produced almost similar reduction of compressibility as sample 20C. Therefore, reusing WGM as partial replacement of cement in DMS could provide beneficial reuse of these materials.

Keywords: Dredged marine soils, cement, bottom ash, palm oil clinker, compressibility

1. INTRODUCTION

Modernization of a country and increasing number of population leads to fast growth of development. Advancement in urban, industrial and tourism sectors resulted in high rise buildings and landmarks. Due to that, more land is required to expand such development. As land become scarce, reclamation of land becomes an important alternative.

Dredged marine soils (DMS) is a soft clay deposits which were excavated during dredging. At present, disposing DMS far into the sea is the common practice here in Malaysia. The annual volume of DMS recorded in 2013 is as shown in Table 1 [1].

Table 1 Volumes of DMS annually in Malaysia

State	Volume (m^3/year)
Perak	120,000
Melaka	120,000
Kelantan	140,000

For every act of dredging, it causes environmental impacts towards the marine environment. Turbidity was caused by the plume of DMS which can be normally seen near the dredger as displayed in Fig.1. Turbidity is part of the inevitable effects of dredging. Other effects are categorized in short and long term impacts as tabulated in Table 2 [2]-[5]. Several studies suggest that reusing DMS as backfill and building materials could be the alternate solutions to the aforementioned problems [6]-[9].

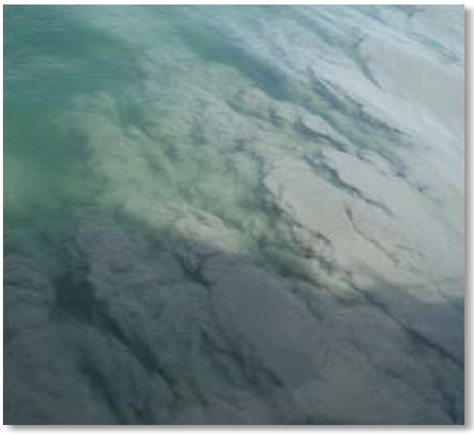

Fig. 1 Plumes of DMS that have caused turbidity

The successful reuse of DMS as backfill material for land reclamation projects include Port of Brisbane (Australia), Tokyo Haneda Airport (Japan) and Changi East (Singapore) [10]-[12].

However, DMS is considered as potential problematic soils which poses low shear strength and high compressibility characteristics. If certain infrastructure were developed on top of this soil, it would be susceptible to non-uniform settlement.

Table 2 Short and long term impacts of dredging

Short term	Long term
• Noise pollution • Turbidity • Removal of bottom fauna	• Habitat loss • Re-suspension of buried contaminated sediments • Exchange of saline and local water

Conventionally, this soft soil can be improved by adding pozzolanic additives such as cement [13]. Soil improvement by adding cement is a popular soil stabilization method and is extensively used since 1970's [14]. Nowadays, alternatives to cement are widely studied to seek eco-efficient cementitious materials. Many researchers had discovered auxiliary pozzolanic additives which consist of industrial by-products such as coal ash (fly ash, bottom ash), rice husk ash, silica-fume, ground granulate blast-furnace slag, and steel slag [15]-[18].

Coal bottom ash (BA) as shown in Fig 2. is a combustion residual waste produced from the power-generation plant. It has the appearance of dark, glassy, porous and irregular shapes. It is also considered as non-combustible waste which has no economic value and ended up disposed either in landfills or pond ash [19]. There is increasing concern on the generated volume of BA which takes up the provided storage space and eventually implies extra cost for new additional space. Therefore, by reusing BA for engineering purposes (structural fill, embankment, road base) could be able to overcome this matter [18].

Fig. 2 Coal bottom ash (BA)

On the other hand, palm oil clinker (POC) as shown in Fig. 3 is a by-product of incinerated solid fuels such as palm fibre and shell for self-generate power in palm oil processing mill [20]. It was obtained in form of large chunks with rough and porous surfaces. In general, POC was disposed in the landfills or used as road covers near the palm plantation due to the fact that POC has little commercial value [21], [22].

Fig. 3 Palm oil clinker (POC)

Unlike BA, the amount of POC produced is yet to trigger alarming concerns. However, alternate waste management must be give thought to before POC fills up the landfill which ended up causing environmental problems. One of the countermeasures is to reduce the by-products by exploring its beneficial reuse. Some of studies reutilized POC as lightweight aggregates in concrete mixture [23], [24].

Both of the aforementioned pozzolanic materials contain pozzolans which react actively along time with the presence of water. Major chemical components which known as oxides consist of silica (S_1O_2), alumina (Al_2O_3), iron (Fe_2O_3) and calcium oxides (CaO). The reactivity of pozzolan in these materials are affected by the amount of the mentioned oxides. However, these pozzolanic materials are not that cementitious by itself. Therefore, by adding WGM partially with cement in soft soil would be able to reduce the amount of cement used.

This study attempts to investigate the compressibility behavior of laboratory prepared DMS admixed with cement and/or WGM. To achieve the objectives of this study, series of oedometer test were carried out on the treated samples. The factor that influenced the compressibility of the soil samples was also investigated such as various percentages of cement and/or WGM.

2. MATERIALS AND METHODS

2.1 Materials and properties

The materials used in this study are DMS, cement, BA and POC. DMS sample was obtained in Kuala Muda, Kedah waterways. The binder used in this study was ordinary Portland Cement, whereas BA was retrieved from Tanjung Bin power plant in Pontian and POC was collected from Keck Seng palm oil processing mill in Masai.

The geotechnical properties of the materials used are tabulated in Table 3. The index value of water content and liquid limit (WC/LL) of DMS used in this study is almost twice its liquid limit. It shows that the soil is soft and in slurry form. Based from Unified Soil Classification System (USCS) [25], DMS was classified as low plasticity silt (ML), whereas BA and POC were classified as particles in the range of sand-gravel size. The particle-size distribution of DMS, BA and POC are displayed in Fig. 4.

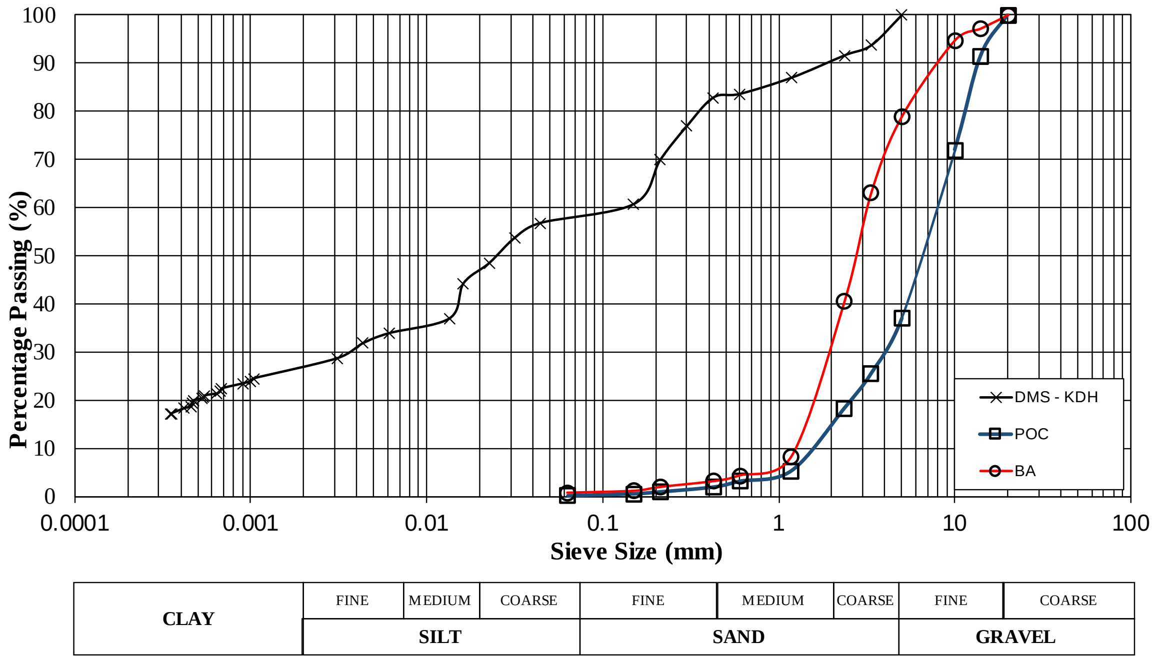

Fig. 4 Particle size distribution of the materials used

Table 3 Properties of materials used

Properties	DMS	BA	POC
Water content, WC (%)	91.96	-	-
Liquid limit , LL (%)	47.70	-	-
Plastic limit, PL (%)	31.50	-	-
Specific gravity	2.57	2.56	2.23
Soil classification	ML	GP	SP

2.2 Sample Preparation and Test Methods

As illustrated in Fig. 5, the soil-phase diagram consists of air, water and solid phases. Each phase indicates mass of each component. In present study, DMS is a fully saturated soil. Hence, major phases inherent in DMS would be water and solid only. Due to the fine-grained nature of DMS, the air phase was negligible since there is a small amount of air inside the void. DMS was admixed together with ordinary Portland cement (C), BA and POC. The percentages of this binder and WGM were determined by the dry weight of soil. The amount of soil and water were remained constant at which the water content was in range of 1.70-2.00 times the liquid limit (LL).

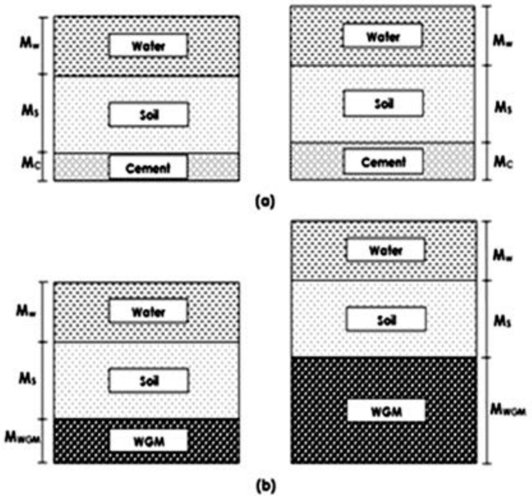

Fig. 5 Soil-phase diagram of (a) cemented soil and (b) WGM-admixed soil

At minimum of 10 % of cement was proved to improve the engineering properties of DMS [26-27]. It was also able to provide significant strength and stability to soil. As for WGM, 50-100 % of BA and POC resulted with higher strength gain and stiffness for a longer curing time [23], [28]. According to [29], the strength and stiffness of soil admixed with BA were influenced by the inter-particle bonding at which the angularity structure of WGM had increased surface-to-surface contact and then further strengthen with cementation caused by pozzolan reaction.

However, since WGM is less cementitious than cement, higher values of WGM used in this study were purposely selected in order to compare the influence of WGM content and its cementation effect. The minimum and maximum percentages of cement are 10 and 20 % by dry weight of soil, whereas the minimum and maximum percentages of WGM are 50 and 150 % respectively. The mix portion of cement, BA and POC are tabulated in Table 4. Note that natural DMS was labelled as “Untreated” and used as controlled sample.

Table 4 Mix proportion of cement, BA and POC

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

The following experimental procedures include sample mixing and sample preparation for oedometer test. DMS sample was left overnight prior to mixing for uniform pore water distribution in the soil. The pre-measured cement and WGM were then added into the soil sample mix. By using kitchen mixer, all of the materials were mixed together for 5 minutes. As finished, the mixture was then filled inside the oedometer cell rings. Layers of fills were tamped thoroughly for equal distribution and then carefully wrapped in cling form. All of the treated samples were cured at room temperature for 7 days, which was based on [30] where the significant shear strength can be witnessed as early as 7 days. The oedometer test was conducted based on BS1377:1990, part 6 [31]. The load weights were accordance to the pre-determined loading (12.5, 25, 50, 100, 200, 400, & 800 kpa) and unloading (800, 400, 100, 25 & 12.5 kpa) sequences.

3. RESULT ANALYSIS & DISCUSSIONS

There are two possible methods to present consolidation settlement plot; namely strain or void ratio plots [31]. Either both method could be used to display the consolidation settlement, however strain plot is most preferable method to be use since the purpose of consolidation test is to determine the stress-strain properties of soil [32]. The values of compression index (C_C) and effective yield stress (σ_y') are tabulated in Table 5. The C_C value determines the compressibility of soil which derived from the steeper slope of the virgin consolidation curve [32], [33]. The σ_y' values denote the break down point of soil inter-particles bond by which indicate the maximum vertical stress that the soil can withstand [34].

Table 5 C_C and σ_y' values.

Sample	C_C	σ_y' (kPa)
Untreated	0.300	23.50
10C	0.027	68.00
15C	0.013	76.00
20C	0.010	220.00
50BA	0.020	32.00
150BA	0.010	42.00
50POC	0.020	36.00
150POC	0.010	58.00
10C100BA	0.012	90.00
15C50BA	0.010	140.00
10C100POC	0.009	65.00
15C50POC	0.010	120.00

3.1 DMS admixed with WGM

By referring Fig. 6, notice that both BA- and POC-admixed samples shown quite similar trend of compressibility. Soil samples treated with 50 % of BA had slightly lower settlement reduction than the 50 % of POC-admixed sample. Based on Table 5, sample 50POC shows higher σ_y' value than the sample 50BA. This proves that sample admixed with 50 % of POC experienced structuration which may induced by cementation [33].

As the percentage of WGM increased up to 150%, both WGM-admixed sample displayed quite alike settlement. The C_C values of 50 and 150 % of WGM-admixed soils show reduction as the WGM dosage increased. It is apparent that soil sample with higher percentage of WGM is able to improve the soil compressibility by providing stiffness. This is due to the presence of large amount of granular materials in the soil sample, the shear resistance was induced by the frictional resistance of WGM. The irregular shape and rough texture of WGM provides inter-particle bond to the contact surfaces. Hence, it gives better interlocked arrangement to the soil skeleton. Also, [29] stated that the higher the degree of interlock in the soil matrix, the greater its shear resistance.

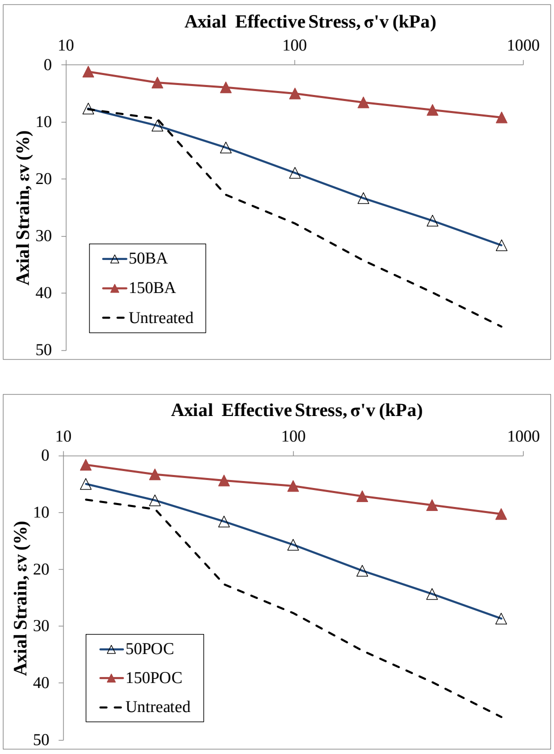

Fig. 6 Compression curves of DMS+WGM

3.2 DMS admixed with Cement

The compression curve of cement-admixed sample is shown in Fig. 7. As expected, the minimum and maximum of 10 and 20 % of cement had significantly reduced the settlement compared to the untreated sample. The σ_y' increased along with the cement content. It takes higher axial effective stress (σ_v') to deformed the soil structure. As the cement content increased, the virgin consolidation slope became less steep and the C_C values reduced. Hence, the inclusion of cement in DMS undoubtedly had improved the soil compressibility.

3.3 DMS Admixed with Cement and WGM

Based from the previous results, higher amount of granular materials and cement had reduced the settlement considerably compared to the untreated soil. Hence, 150 % of WGM and 20 % of cement were omitted from the following homogenous samples. The exclusion of the stated materials is to prevent the homogenous samples to become stiff with high content of WGM and cement.

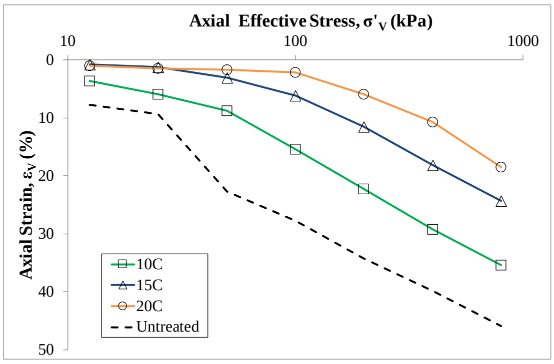

Fig. 7 Compression curves of DMS+Cement

Higher percentages of WGM could reduce the settlement almost similar to the effect of 10–15 % cement-treated sample. Therefore, WGM as minimum of 50 % and maximum of 100 % were chosen. As for cement, the minimum and maximum of 10 and 15 % were admixed in the homogenous samples. Samples 10C100BA and 10C100POC denote mixture of low cement and high WGM content. Contrariwise, samples 15C50BA and 15C50POC denote mixture of high cement and low WGM content. Theoretically, the strength of homogenous sample can be influenced by two factors; i) development of cementation bond and ii) frictional resistance induced by inter-particle bond [29].

As shown in Fig. 8, both WGM-admixed samples resulted with different settlement. Note that the data plot of samples 20C and untreated were also included in graphs for comparison. Samples 10C100BA and 15C50BA show almost identical trend of compressibility. Based on Table 5, the values of C_C and σ_y' were reduced and increased respectively along the increment of cement and decrement of BA percentages. Sample with less cement and more BA content displayed lower settlement reduction than sample with more cement and less BA content. Result from [35] stated that the inclusion of 60 % and more BA in soil-cement mixture would displayed brittleness characteristic. This explained well of the higher settlement that sample 10C100BA had experienced.

Initially, the compression curves of samples 10C100POC and 15C50POC had decreased similarly until certain applied stress then ended up with different magnitude of settlement. As the cement content increased and POC percentages decreased, the C_C and σ_y' values increased. Sample with more cement and less POC resulted with bit higher settlement than sample with less cement and more POC.

Obviously, samples 15C50BA and 10C100POC had provided lower settlement than sample with 20 % of cement. It can be concluded that the addition of WGM in cemented soil able to produced similar and more enhanced settlement as cemented soil, thus reduced the usage of cement.

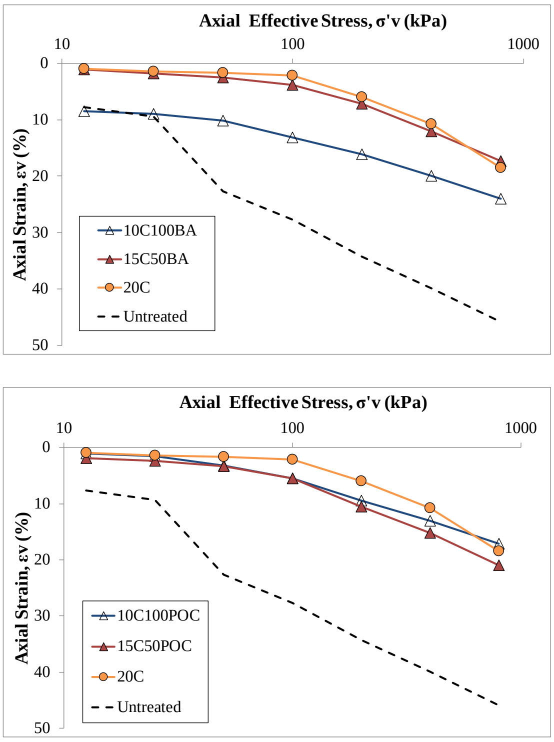

Fig. 8 Compression curves of DMS+cement +WGM

4. CONCLUSIONS

This study investigated the physical and mechanical properties of homogeneous mixture consists of DMS, BA and POC. Inclusion of WGM in cemented DMS is to provide beneficial reuse of these materials. Series of samples were tested by oedometer test and the following conclusions can be drawn.

1. Inclusion of 50 and 150 % of WGM have resulted reduction in compressibility than untreated sample. Higher percentage of WGM shows higher σ_y’ and lower C_C values. Better interlocked arrangement of soil skeleton due to high amount of WGM governed the stiffness and shear resistance of the WGM-admixed samples.
2. As expected, the minimum and maximum of 10 and 20 % cement had significantly reduced the settlement better than WGM-admixed sample. Therefore, the effect of homogenous sample consists of cement and WGM was tested.
3. Homogeneous samples of 15C50BA and 10C100POC produced similar and reduced more settlement as sample 20C. The partial inclusion of WGM with low percentage of cement able to provide similar settlement improvement as high percentage of cemented soil.
4. Hence, concluded that reusing WGM could be suitable as auxiliary additives to cement and provide better waste management for DMS and WGM.

5. ACKNOWLEDGEMENTS

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