Journal of Civil Engineering Research 2014, 4(3A): 48-53
DOI: 10.5923/c.jce.201402.07

Solidification Potential of Fine-Grained Dredged Marine Soils: Water-Binder Ratio Effects

Amira Azhar[1], Chee-Ming Chan[2,*], Ahmad Tarmizi AbdKarim[1]

[1]Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia
[2]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia

Abstract Dredging activities are important to ensure safe navigation of ships and vessels at ports, harbors, and navigational channels. Dredged marine soils (DMS) is a valuable resource even though not commonly practice. The use of dredged material has a major contribution to make to sustainable development and can reduce the quantities of primary resource needed for activities such as construction and habitat creation. Solidification is a method that aims to improve the engineering properties of soil such as soil strength. Soil stabilization involves the use of stabilizing agents or binder materials in soft soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The fine-grained DMS sample collected from Marina, Melaka was used in this study. According to Unified Soil Classification System (USCS), the DMS was classified as high plasticity clay (CH). The amount of DMS that will be mixed with the binders was calculated based on water-binders (water-cement) ratio. Calculation for the amount of binders (OPC and BA) for each mixture was calculated from mass of dry sample and moisture content of the sample. The water binder ratios of the samples are 1, 3 and 5.Unconfined compressive strength tests were performed to determine stability of the solidified samples to withstand overburden loads and to determine the increment of strength. The water-binder ratio gives high impact on the increment of the DMS strength. As the water-binder ratio decrease, the DMS strength will increase. Curing days also give effects to strength of the samples. The result shows that strength increase with respect to time.

Keywords Dredged marine soils, Solidification, Water-binder ratio

1. Introduction

Dredging activities are important to ensure safe navigation of ships and vessels at ports, harbors, and navigational channels. Dredging activities generates large volumes of dredged marine soils (DMS). DMS consist of clean gravel and sands or contaminated fine-grained soils. The fine-grained soils may pose high risks to human health and the environment [1, 2]. Contaminants in DMS can be stabilized or removed by treatment techniques to make it suitable for reuse [3].

Dredged marine soils are a valuable resource even though not commonly practice. The use of dredged material has a major contribution to make to sustainable development and can reduce the quantities of primary resource needed for activities such as construction and habitat creation. Some countries do already make extensive use of dredged material, for example in Japan in 2003 more than 90% of dredged material was used [4].

Solidification is a method that aims to improve the engineering properties of soil such as soil strength. There are two types of stabilization that are commonly used nowadays that are mechanical stabilization and chemical stabilization. Soil stabilization involves the use of stabilizing agents or binder materials in soft soils to improve its geotechnical properties such as compressibility, strength, permeability and durability. The components of stabilization technology include soils and binders. The binders used normally are cementitious materials [5]. The factors that affect the physical properties of mixing of soil-cement are including the soil type, quantity of cement, degree of mixing, curing time and dry density of the compacted mixture [6].

Solidification binders are materials that form cementitious composite materials when in contact with water or in the presence of pozzolanic minerals that reacts with water. The material used for cementitious material is also known as binder. The commonly used binders are cement, lime and fly ash [5]. Ordinary portland cement (OPC) is a mechanical additive that can be used for soil solidification. OPC is a common type of fine powdery cementitious building material. When mixed with water and sand (or gravel), it turns into masonry mortar (or concrete). After a series of complex internal reactions (hydration), the mixing would sets like a stone.

Bottom ash is produced as a result of burning coal in a dry

* Corresponding author:
chan@uthm.edu.my (Chee-Ming Chan)
Published online at http://journal.sapub.org/jce

bottom pulverized coal boiler. It consists of non-combustion materials. Raw bottom ash is a granular material that consists of a mix sand, stone, glass, porcelain, metals, and ash from burnt materials. The non-combustion material from a dry bottom boiler consists of 20 % of bottom ash. Generally, bottom ash is a porous, glassy and dark gray material with a grain size similar to that of sand or gravelly sand.

Successful modern soil stabilization techniques are necessary to assure adequate subgrade stability, especially for weaker soils [7]. The increase of cement content and curing time caused significant improvement of unconfined compressive strength as well as stiffness of the treated clay [8].

There are many advantages of soil stabilization such as improved the strength of soil and helped to reduce soil volume changes due to temperature or moisture. A part from that, soil stabilization also can improve the soil workability, improves durability of soils, reduce the cost and conserve the energy. Stabilization also can reduce the need for borrowing pit materials. It also can reduce the need for landfill site for dumping poor materials [9].

Abram's law state that the strength development in concrete technology depends on water-to-cement-ratio [10]. Water-cement (water-binder) ratio of soil was used by taking considered on this law and characteristic of soil and cement [11]. The water–binder ratio is the ratio of weight of water to the weight of binder used in a soil mix. The water-binder ratio has an important influence on the quality of soil mixing that was produced. A lower water-binder ratio will leads to higher strength and durability. Soil-binder ratio is a compacted mixture of pulverized soil, portland cement and water. As the cement hydrated it will forms a hard, durable and low cost paving materials. Soil-cement will undergo chemical reaction between cement and water just like concrete mixture. Water must be available during this chemical reaction in order for soil-cement to gain strength [12].

2. Materials and Methods

2.1. Materials

The fine-granined dredged marine soils (DMS) sample for this study was collected from Marina (Melaka). Most of the dredging activities in Malaysian ports are managed by Marine Department of Malaysia including Marina, Melaka. DMS was collected by backhoe dredger at a depth of 3.5-6.5m from sea level. The amount of DMS collected at Marina, Melaka is about 120,000 m^3. The samples collected were put in sealed plastics bag to avoid moisture loss during transportation. Samples were stored indoors to avoid direct sunlight and heat. Figure 1 show typical picture of dredged marine sediments.

The characteristics of fine-grained dredged marine soils (DMS) samples collected from Marina Melaka were shown in Table 1. The natural moisture content of DMS is 142.97%. According to the study conducted by Grubb, moisture content for dredged marine sediments is between 100%-200% [13]. According to Unified Soil Classification System (USCS), the DMS was classified as high plasticity clay (CH).

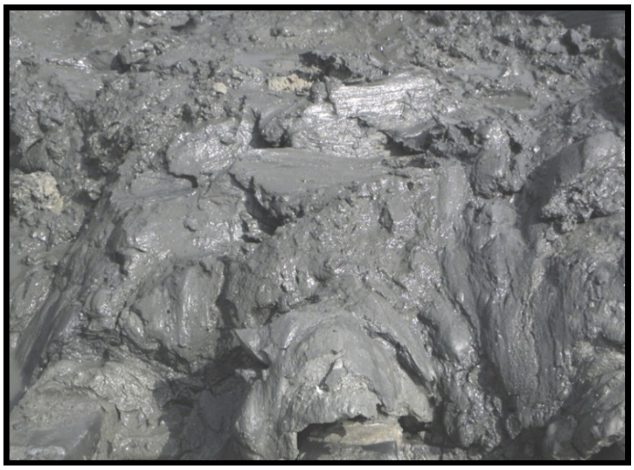

Figure 1. Typical picture of dredged marine sediments

Table 1. Physical and Chemical Properties of Dredged Marine Soil

Properties	Marina
Moisture content (%)	142.97
Liquid limit (%)	65.00
Plastic limit (%)	50.46
Plasticity index (%)	14.54
Particle density (%)	2.56
Loss on ignition	9.49
pH	8.32
Soil classification	CH
** CH = high plasticity clay	

The binders used in this study were ordinary portland cement (OPC) and bottom ash (BA). Portland cement was used as cementing agent in this study. OPC used in this study is Portland Fly Ash cement with a high-quality silica rich coal fly ash. Type II OPC was used in this study. Bottom Ash (BA) was used in this study in order to reduce the usage of cement in solidified soils. Bottom Ash was obtained from Tanjung Bin, Johor. Table 2 summarised the properties of the binders.

Table 2. Properties of Binders

Properties	Binders	
	Ordinary Portland Cement (OPC)	Bottom Ash
Moisture content (%)	Free from moist	Negligable amount of moist
Particle density	1.26	2.30
pH	12.35	9.17

2.2. Methods

The mixing of fined-grained dredged marine soils (DMS) was conducted based on water-binder ratio (ww/wb) which was adapted from water-cement ratio that was used concrete technology. The first step to determine the water-binder ratio is to obtain the natural water content of the sample. Natural water content of DMS is 142.97%. The amount of wet DMS can be obtained based on the dry weight of DMS. The water-binder used in this study was 1, 3 and 5. Based on the water-binder ratio that had been set up, the calculation of the amount of ordinary Portland cement and bottom ash can be obtained. Table 3 show the percentage of binder used in this study. Table 4 show the calculation of DMS mixture with binder based on the water-binder ratio.

Table 3. Percentage of binders

Water-binders ratio	Percentage of Cement (%)	Percentage of Bottom Ash (%)
1	100	0
3	75	25
5	50	50
	25	75

Table 4. Calculation of DMS mixture

	Example of calculation	Mass of sample
Wet DMS	Calculation based on 100g of dry DMS Natural moisture content = 142.97% $M_1 = (\frac{M_c}{100} \text{ x } M_2) + M_2$ M_1 = Mass of wet DMS M_2 = Mass of dry DMS M_c = Natural moisture content of DMS $M_1 = (\frac{142.97}{100} \text{ x } 100g) + 100g$ =242.97g	Mass of wet DMS = 242.97 g
Mass of binder	Calculation based on water-binder ratio = 3 Based on natural moisture content test, mass of water = 17.82 g Water-binder = $\frac{mass\ of\ water}{mass\ of\ binder}$ $3 = \frac{17.82}{mass\ of\ binder}$ Mass of binder = 5.94 g	Mass of binder = 5.94 g
Mass of OPC and BA	Calculation based on 75% of OPC + 25% of BA Mass of OPC = $\frac{OPC\ (\%)}{100\%\ of\ binder}$ x mass of binder $= \frac{75\%}{100\%}$ x 5.94 g = 4.46 g Mass of BA = $\frac{BA(\%)}{100\%\ of\ binder}$ x mass of binder $= \frac{25\%}{100\%}$ x 5.94 g = 1.49 g	Mass of OPC = 4.46 g Mass of BA = 1.49 g
Total mass of mixture	Total mass of mixture =Mass of wet DMS +mass of OPC + mass of binder =242.97 + 4.46 + 1.49 =248.92 g	Total mass of mixture=248.92 g

For sample preparation, the original DMS sample was mixed thoroughly by using the food mixer and stored for 24 hours to ensure the sample was homogenous. While cement and bottom ash was dried in oven to ensure moisture free and kept at tight container. After 24 hours the mixing was done. All of DMS samples were mix together with the binders at a time. The mixture was first mixed using hand then proceeds with food mixer for 5 minutes. The steps were repeated until all cement and bottom ashes were fully mixed with the DMS.

The test used in this study is unconfined compression tests (UCS). Unconfined compression test was conducted according to BS 1377-7:1990, Clause 7. The sample was then compacted in three layers inside cylindrical split mould. The cylindrical mouldused is 38 mm diameter and 76 mm height. After finished the moulding, the weight, diameter and height of the samples was measured. The samples were then wrapped with the plastic wrapper to ovoid the loss or gain of the moisture content. The samples then stored in plastic container and air cured at room temperature (25 ± 5°C) for 3, 7, 14, 28 and 56 days.

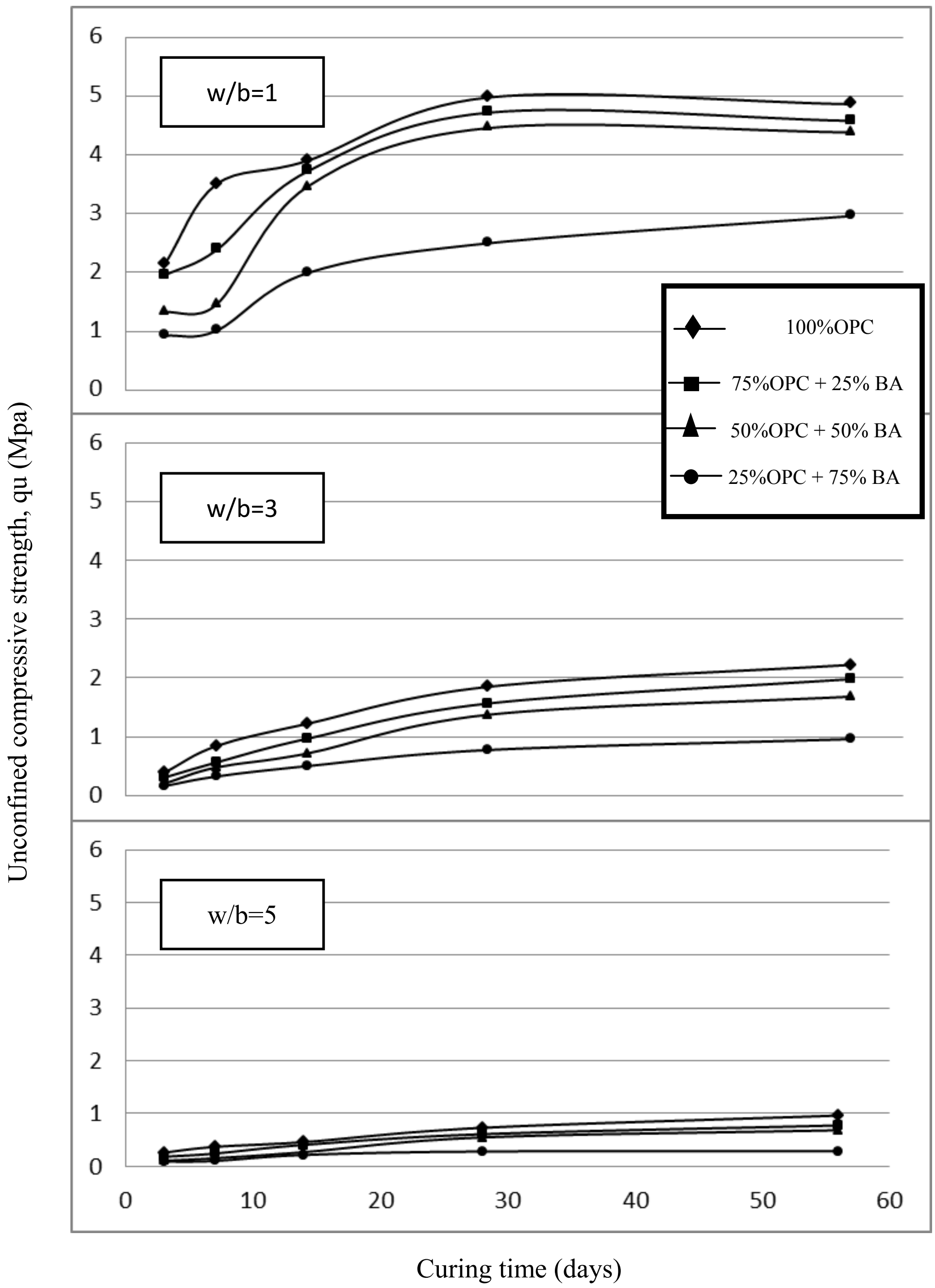

Figure 2. Effects of curing day effects on unconfined compressive strength

3. Result and Discussion

Without any solidification process or treatment, the natural dredged marine soils (DMS) has low undrained shear strength. The value of shear strength of natural DMS is 2-4 kPa. The solidification process is needed to improve the properties of DMS. Unconfined compressive strength (UCS) tests were performed to determine the strength of the solidified samples to withstand the overburden load. The degree of reaction between soil-binder mixture and hardening rate can also be determined from unconfined compressive strength test.

Figure 2 shows the effect of curing on unconfined compressive strength based on water-binder ratio (w/b). The water-binder ratio affected the increment of the DMS strength. As can be seen in Figure 2, the sample with w/b=1 has the highest strength. For w/b=1 with 100% of OPC, the graph can be seen increase rapidly starting from day 3 and has small increment after day 14 until day 28. The same increment can be seen for sample w/b=1 with 75%OPC + 25% BA and for sample with 50%OPC + 50%BA. At day 56, the strength of solidified DMS decreased. For the 25%OPC + 75%BA, the sample strength increase continuously.

For w/b=3, the sample with 100% of OPC, 75%OPC + 25% BA, 50%OPC + 50%BA and 25%OPC + 75%BA have slightly increased from day 3 to day 56. From the pattern of these three graphs it can be estimated that, the strength will be increase even after 56 days. Although the strength of the samples with w/b=3 is lower compared to samples with w/b=1, but it is suitable to use to solidify the samples. As for w/b=5, the graph shown that the strength increase steadily from day 3. It was observed that, as the water-binder ratio decrease, the strength increase rapidly.

The mixing percentage of the binders also affected in strength improvement of the samples. As the percentage of the cement increased and the percentage of the binder decreased, the strength of solidified samples also increased. Curing days also give effects to strength of the samples. The result shows that strength increased with respect to time. As the time increase the strength also increases. Initially the gain in strength in high but it started to level after day 14. As the age of the sample increases, the different in strength of each sample tends to gets smaller. Generally, it can be observed that, longer period of curing time results in greater strength gain.

The hydration of the OPC occurs from day 3 to day 14. The improvement of the strength of solidified soils is due to the hydration of the water. The water in samples was used to form ettringite. The ettringrite will bind the soil particle and binder to make the soil become harder and stronger. The study conducted by Horpibulsuk *et. al* (2003) observed that when cement and clay interact with water, it will be grouped the clay particles and cement particles together. The binders or cementitious materials can solidified the soils and modify their properties. This is due to cation exchange, flocculation and pozzolonic reactions. Hydration agents like calcium oxide (CaO), aluminium oxide (Al_2O_3) and ferum oxide (Fe_2O_3) in the cement increased the strength of DMS samples [13]. Initially the gain in strength of DMS samples is high but it started to level off after day 28. For w/b=3 and w/b=5, only small increment in strength can be seen after day 28. This is due to pozzolonic reaction. The present of CaO, Al_2O_3 and Fe_2O_3 will create pozzolonic reaction. The combining of water and ordinary portland cement will create the calcium silica hydrate (CSH). This reaction will increase the strength of the samples.

Based on the results obtained, it can be said that the optimum water-binder ratio is w/b=3. Even for the lowest percentage of cement used, the strength of the sample reached 1Mpa after day 56. The strength of the sample with w/b=1 is too high for solidified sample. It is due to the over mixing design and not economical since large amount of cement and bottom ash were used. The ratio for w/b to the DMS is about 1:1. It is not suitable to be used in construction since it would consume large amount of money.

4. Conclusions

The water-binder ratio affect on the increment of strength of dredged marine soils (DMS). It was observed that, as the water-binder ratio decrease, the strength increase rapidly. The mixing percentage of the binders also affected in strength improvement of the samples. As the percentage of the cement increased and the percentage of the binder decreased, the strength of solidified samples also increased. Curing days also give effects to strength of the samples. The result shows that strength increase with respect to time. As the age of the sample increases, the different in strength of each sample tends to gets smaller. Generally, it can be observed that, longer period of curing time results in greater strength gain. The improvement of the strength of solidified soils is due to the hardening process of the cement.

ACKNOWLEDGEMENTS

Special thanks goes to Jabatan Laut Malaysia and Malaysian Maritime & Dredging Corporation Sdn. Bhd (MMDC) for giving us access to the sampling site. Besides that, we also would like to thanks RACE Vot 1115, Science Fund Vot S025 and Geran Insentif Penyelidik Siswazah (GIPS) for financial support.

REFERENCES

[1] B. Rekik, and M. Boutouil, "Geotechnical properties of dredged marine sediments treated at high water/cement ratio," Geo-Marine Letters.

[2] A. Maher, W.S. Douglass, F. Jafari and J. Pecchioli, "The Processing and Beneficial Use of Fine-Grained Dredged Material: A Manual for Engineers," 2013.

[3] CEDA, "Dredging and Environment: Moving Sedimenets in Natural System," CEDA information paper, December 2009.

[4] CEDA, "Dredged Material as a Resource: Options and Constrain," CEDA information paper, June 2010.

[5] G.P. Makusa, "Soil Stabilization Methods and Materials in Engineering Practice," Luleå University of Technology, 2012.

[6] E.J. Yoeder, "Principles of Soil Stabilization: Technical Report," 1957.

[7] T. E. Kowalski and D. W. Starry, "Characterization and improvement of soils and materials session," Annual Conference of the Transportation Association of Canada Saskatoon, Saskatchewan, 2007.

[8] A. H. M. Kamruzzaman, S. H. Chew and F. H. Lee, "Engineering behaviour of cement treated Singapore marine clay," Department of Civil Engineering, National University of Singapore, 1918.

[9] S. Vitton, "Introduction to soil stabilization. Understanding the basic of soil stabilization: An Overview of Material and Technique", 2006.

[10] D. A. Abrams, "Design of concrete mixtures." Bulletin I structural Material Research Laboratory, Lewis Institute, Chicago, 1918.

[11] S. Horpibulsuk, N. Miura, and T. S. Nagaraj, "Clay-water/ cement ratio for cement admixed soft clays." Journal of Geotechnical and Geoenvironmental Engineering. pp. 187-192, 2005.

[12] G. J. Mirtl, " Soil-cement construction," Town affair meeting of The Connecticut Society of Civil Engineers, Inc., Wethersfield, Conn., 1964.

[13] A.K. Ahmad Tarmizi, A.L. Ab. Aziz and T. MohdRaihan, "The Remediation of lead contaminated soil by the solidification/stabilization method" Proceeding of KUiTTHO Research Seminar, Kolej Universiti Tun Hussein Onn, Malaysia, 2005.

[14] S. Horpibulsuk, N. Miura and T. S. Nagaraj, "Assessment of strength development in cement-admixed high water content clays with Abrams` law as a basis," 2003.