IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 2 Ser. I (Mar. - Apr. 2019), PP 41-47
www.iosrjournals.org

Rheological Characteristics of Stabilized Dredged Materials at High Water Contents

Shoaib Ahmed[1], Yin Jie[2], Oliver C. Waka[1]
Postgraduate Student[1],Department of Civil Engineering, Jiangsu University, China
Assistant Professor[2],Department of Civil Engineering, Jiangsu University, China
Corresponding Author: Shoaib Ahmed

Abstract: *This paper presentsthe experimental results of the rheological behavior of cement stabilized dredged materials (DM) at high water contents. Slurries used for experiments were dredged from Baima Lake of Huai'an city and Tianjin Port of Tianjin city in China to prepare DM samples with various initial water contents (1.5~3.5 times of liquid limit). Various amounts of Portlandcement in different proportions (50~200 kg/m^3) were added to stabilize the specimens. A series of laboratory tests were conducted on the treated specimens includingflow tests and viscosity tests. Test results have indicated that the flow value of the cement-stabilized DM increases with increasing initial water content and are independent of soil sources. DM samples stabilized at higher cement content has lower flow value. Cemented-DMs and non-treated DMs both behave as Bingham fluid and they are independent of cement content used for stabilization. Dynamic shear force and viscosity coefficient increase significantly due to cement-stabilization, and a power function relationship between the flow value and dynamic shear force of DM is presented.*

Keywords: *Dredged Materials; cemented dredged materials; initial water content; flowability; viscosity*

Date of Submission: 26-02-2019 Date of acceptance: 12-03-2019

I. Introduction

Materials dredged from the bed of lakes, rivers, harbors, and other waterways are termed as dredged materials (DMs); the process is called dredging, which is essential to keep waterways navigable and prevent rivers from flooding. At the same time, the demand for raw materials has risen significantly in coastal development projects due to rapid growth and increased human population in coastal cities. Therefore, there is a need to re-use the dredged soils that are produced in the result of dredging works. The dredged materials are considered as waste and disposed into deep oceans and land disposal sites (Bian, Cao, Wang, Ding, & Lei, 2017). Recent studies have mentioned that about 100 million m^3 of dredging materials were disposed of annually into the ocean alone in China (Y. Huang, Dong, Zhang, & Xu, 2017), which put extra demands on ocean and new land disposal sites. In addition, ocean disposal has hazardous effects on aquatic life and the environment.

In general, dredged soils are considered as waste materials due to poor strength properties and their water contents tend to be higher than their liquid limits (G.-Z. Xu, Gao, Hong, & Ding, 2012). Several studies have been carried out to stabilize the dredged soils adding cementitious agents (e.g., lime, cement, polymer and fly ash) into raw dredged materials and their beneficial effect on the performance of soft soils are widely documented (Chiu, Zhu, & Zhang, 2009; Y. H. Huang, Dong, Zhan, & Guan, 2014; Kang, Tsuchida, & Athapaththu, 2016; Kasama, Zen, & Iwataki, 2006; Lee, Lee, Chew, & Yong, 2005; Shi, Chen, Nimbalkar, & Liu, 2017; Tsuchida & Tang, 2015; G. Xu, Gao, Yin, Yang, & Ni, 2014; Yu, Yin, Soleimanbeigi, Likos, & Edil, 2016; Yu, Yin, Soleimanbeigi, & Likos, 2017). For instance, (Tsuchida & Tang, 2015) mentions the potential benefit of stabilized dredged materials in the expansion of Haneda Airport; some 49 million m^3 of cement treated dredged soils were used as a filling material, the project was completed in 2010. The use of cement to treat the dredged materials has certain advantages over other cementitious agents; 1) quick stabilization, 2) does not need mellowing time, and 3) provides a non-leaching platform (Sariosseiri & Muhunthan, 2009).

Recent years have seen the increased use of stabilized dredged soils in geotechnical works such as filling material, cement-soil grout, and foundation soils. This development has made it necessary to consider the rheology of cemented-soils, which is related to the calculation of deformation of soil structure or foundation and strength analysis. It should be noted that most of the recent studies have focused on water contents of cemented-DM that are less than two times of their liquid limit; and the typical water content of DM in a storage yard in China is two to three times liquid limits (G. Xu et al., 2014). In addition, many studies have focused on the mechanical behavior of cement stabilized dredged materials, such as strength and compressibility (Y. Huang, Zhu, Qian, Zhang, & Zhou, 2011; Kang et al., 2016; Lee et al., 2005; Sariosseiri & Muhunthan, 2009; Tsuchida

& Tang, 2015; Wei, 2000; Zentar, Dubois, & Abriak, 2008). However, research studies on the mechanism and constitutive modeling of rheological characteristics of stabilized dredged materials are still lacking. Therefore, in this paper, the rheological characteristics i.e. viscosity and flowability of the cement stabilized DM are presented, especially for those DMs with high water contents. Specimen DMs having high initial water content taken from two different sites located in China were stabilized with cement and suitable tests were conducted to understand the rheological behavior of cement-stabilized-DM and recommendations are put forward in relation with the beneficial use of the dredged materials.

II. Materials

In this study, samples of dredged materials (DM) were obtained from two different places in China: 1) Baima Lake in Huai'an city of Jiangsu Province; 2) Tianjin Port in Tianjin city. For simplicity, two sources of DMs were designated as Baima Lake DM and Tianjin Port DM, respectively. Table 1 summarizes the index properties of the two DMs samples. Plasticity Chart based on the USCS classification (Soil & Rock, 2011) indicates that Tianjin Port DM can be classified as CL (clay of low plasticity) and Baima Lake DM as CH (clay of high plasticity) as shown in Fig. 1. It can be seen that twospecimens slightly lie above the A-line, defined by PI=0.73(LL–20), where PI represents the plasticity index and LL is the liquid limit. Ordinary Portland Cement (OPC) produced, locally, in Jiangsu Province was used for the treatment of the dredged materials.

Table1: Index properties of two dredged materials

Material	G_s	LL (%)	PL (%)	PI (%)	d<0.005 mm (%)
Baima Lake DM	2.68	65.3	27.9	37.4	47.5
Tianjin Port DM	2.70	31.2	15.9	15.3	39.1

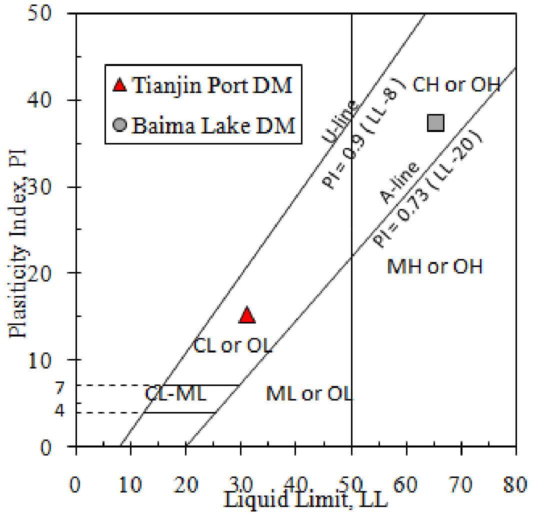

Fig. 1: Plasticity chart for two DMs

III. Methods

In China, the most common method used for dredging is "Cutter Suction". The slurry obtained through cutter suction dredgers have a higher initial water content in comparison with other dredging methods. Table 2 summarizes the different DM specimens with different initial water and cement (by weight) content, in this study, to investigate the rheological behavior of stabilized DM.

3.1 Flow tests

Flow value test determines the "flow consistency" of dredged materials; a material property which relates to the rheology of the material. Therefore, flow value is the main indicator to describe the flow consistency of the dredged materials. In this study, JHS A313-1992 standard flow test (Test, 1992) was used to estimate flow value. This standard is equivalent to the procedure described by the ACI Committee 229 (Rajendran, 1994) and suggest using a 75 × 150 mm open-ended cylinder.Following the standard slump flow test, the cylinder was gently raised and the slurry forms a collapsed body on the smooth Plexiglas base plate. Two measurements of spread diameter, at 90 degrees apart, were averaged, and the average of the two was taken as slump flow value.

3.2 Viscosity test

The rotational viscometer (NXS-11B, China), was used to determine the rheological properties of DM and stabilized DM. It is mainly composed of an inner cylinder rotating in a stationary outer cup. DM samples were filled in between the inner cylinder and an outer cup, and as the inner cylinder start rotating, the filled material will be sheared. Inner cylinder with larger dimensions records readings more accurately because large torque is measured. On the contrary, when the water content is decreased, smaller inner cylinder are suitable because the torque required to rotate large inner cylinder is above the allowable limits. Therefore, prior to the tests, all the sludge samples were thoroughly mixed to ensure complete homogenization, and then appropriate inner cylinder was used. A fresh sample was loaded into the annular gap of the concentric cylinder viscometer. The apparent viscosity of cured DM sludge as a function of shear rate was measured.

Table 2: Summary of a testing program of cement-treated DMs

Source of DMs	Initial water content w_0(%)	w_0/LL	Cc (kg/m^3)
Baima Lake	97.0	1.5	0, 50, 150
Baima Lake	136.5	2.1	0, 50, 100, 150,
Baima Lake	172.2	2.6	0, 50, 150
Baima Lake	215.3	3.3	0, 50, 100, 150
Tianjin Port	65.1	2.1	0, 150
Tianjin Port	81.3	2.6	0, 150
Tianjin Port	97.2	3.1	0, 50, 100, 150, 200
Tianjin Port	110.3	3.5	0, 150

Note: cement content C_c (weight of cement in 1m^3 oftreated soil, in kg/m^3)

IV. Results And Discussions

4.1 Flowability

Flow test determines the “flow value” of dredged materials; a material property which relates to the rheology of the material. Therefore, the flow values for stabilized DMs with different cement contents and initial water contents for Baima lake DM and Tianjin Port DM were studied and results are shown in Figs. 2(a) and 2(b), respectively. C50 (50 kg/m^3), C100 (100 kg/m^3), and C150 (150 kg/m^3) indicate the cement content used for stabilized DM’s. Figs. 2(a) and 2(b) reveal two important findings: 1) the flow value of the stabilized DMs increases with increasing initial water content; 2) dredged material stabilized with higher cement content has comparatively lower flow value. The Ministry of Land, Infrastructure, and Transport of Japan (MLIT) specifies that the flow value of dredged sludge needs to be greater than 16 cm. Therefore, the flow value of minimum 16 cm is considered as standard. In addition, Fig. 2 (a) shows that the flow value increased significantly when w_o/LL changes from 1.5 to 2.5 and change is insignificant when w_o/LL changes from 2.5 to 3. Fig. 2(b) shows a similar trend that change is significant in the beginning and slows down with the increase of initial water content. For instance, a quick increase in flow value when w_o/LL changes from 2 to 3 and slows down when w_o/LL changes from 3 to 3.5. However, the rate of increase of flow value with respect to initial water content is the same for all stabilized DM samples.

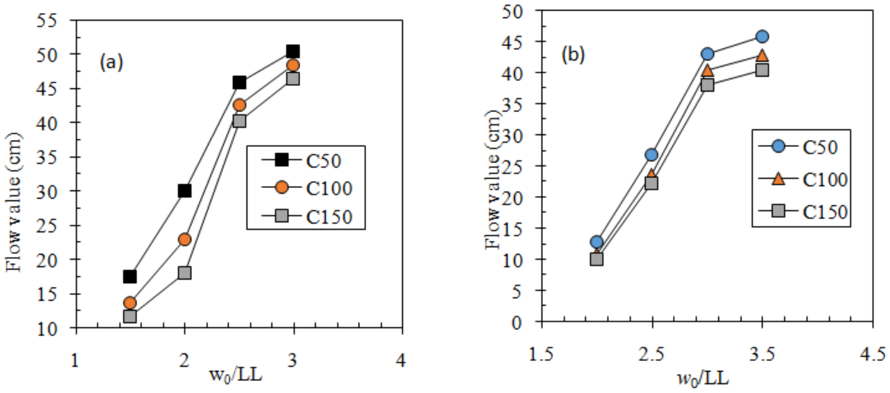

Fig. 2: Variation of flow value with w_0/LL for (a) Baima Lake and (b) Tianjin Port stabilized DMs

4.2 Viscosity

Sir Isaac Newton described the viscosity (μ) with a simple linear relationship between shear stress (τ) and shear strain (γ). In general, the viscosity models can be divided into two: Newtonian model and non-Newtonian models. For the Newtonian fluids, the stress-strain curve is linear with the intercept at the origin and can be expressed mathematically by equation (1). An exception to this rule is Bingham plastics, which resist finite stress (τ_y) prior to the motion. They are strictly non-Newtonian fluids and can be expressed mathematically by equation (2). The reason for this finite stress or yield stress (τ_y) is the existence of shear strength (cohesion) between soil particles.

$$\tau = \mu\gamma \qquad (1)$$

$$\tau = \tau_y + \mu\gamma \qquad (2)$$

Some researchers show that the yield stress and viscosity are affected by various factors, such as includes water content, particle size, and mineral composition (Thomas, 1963). In this paper effect of water content on rheological properties was conducted on treated and non-treated DMs. Fig. 3 shows the variation of viscosity coefficient μ and the dynamic shear force τ_0 with initial water content w_0 for Baima Lake and Tianjin Port DMs. It can be seen from Fig. 3 that both μ and τ_0 exhibit an exponential relationship with w_0, which can be expressed as,

$$\mu = a{\cdot}e^{bw_o} \qquad (3)$$

$$\tau_0 = c{\cdot}e^{bw_o} \qquad (4)$$

Where e is the natural logarithm, w_0 is the initial water content of DM, and *a*, *b*, and *c* are the fitting parameters. Table 3 lists the fitting values for a, b and c. It is shown that both μ and τ_0 decrease with the increasing initial water content. The difference between Baima Lake and Tianjin Port DM is due to the different liquid limit values of two DMs.

Table 3: Fitting parameters for Eqs.(1) and (2)

Sources	*a*	*b*	*c*
Baima Lake DM	12.6	-0.04	2892.6
Tianjin Port DM	7.4	-0.06	2105.4

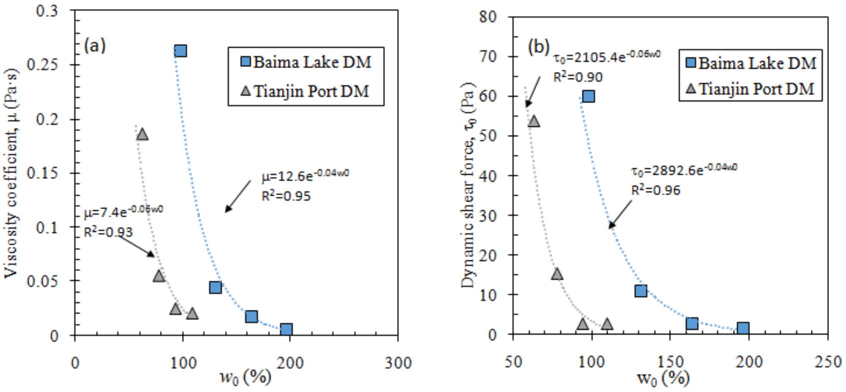

Fig. 3: Variation of (a) viscosity coefficient and (b) dynamic shear force with initial water content for DMs

Fig. 4(a) gives the viscosity curves for Tianjin-DM at different initial water contents. It is evident that the DMs with less initial water content has higher initial yield stress. In addition, the viscosity curves for DMs with lower initial water contents lie above those DMs with higher initial water contents. Therefore, DM at a water content of 65.1% has the highest initial yield stress and the respective curve lies above the all other DMs. Fig. 4(b) presents the viscosity curves for stabilized Tianjin-DMs at various cement contents. It clearly reveals that cement content has significantly improved the viscosity. For instance, when the water content is 97.2%, the shear stress of non-treated DM is found to be in the range of 5-15 Pa with the increasing shear rate. Also, at the same water content of 97.2%, the initial yield stress of cement (C50)-stabilized-DM has increased to 40 Pa, and the shear stress found to be in the range of 40-65 Pa with increasing shear rate. The viscosity curve of stabilized-DMs with higher cement content are located above those with less cement content.

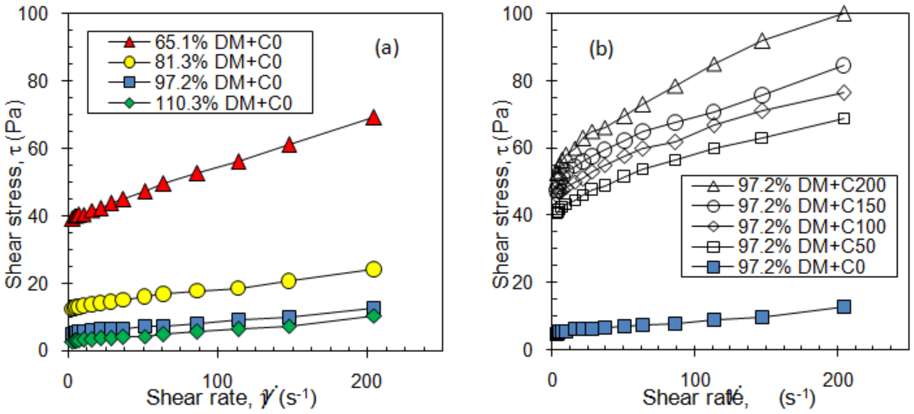

Fig. 4: Viscosity curvesof (a) raw DMs with different water contents and (b) stabilized DMs with different cement contents for Tianjin PortDMs

Fig. 5(a) illustrates the relationship of the viscosity coefficient of cement stabilized DM at different initial water contents. It is evident that the viscosity coefficient and dynamic shear force decreases significantly with increasing water content. Similarly, dynamic shear force decreases significantly with increasing water content, as shown in Fig 5(b). However, as compared with DM in Fig. 3, we can see that the viscosity coefficient and the dynamic force are increased considerably due to stabilization with cement content. This observation is in line with the results obtained in Fig. 4(b), where the shear stress value increased for stabilized DMs at w_0=97.2% and viscosity curve follows Bingham fluid. The gap in the curve between two stabilized-DMs is due to the difference in their initial water content. Tianjin-DM has less initial water content than Baima-DM, and therefore Tianjin-DM particles tend to be thicker and have more water absorbing capacity.

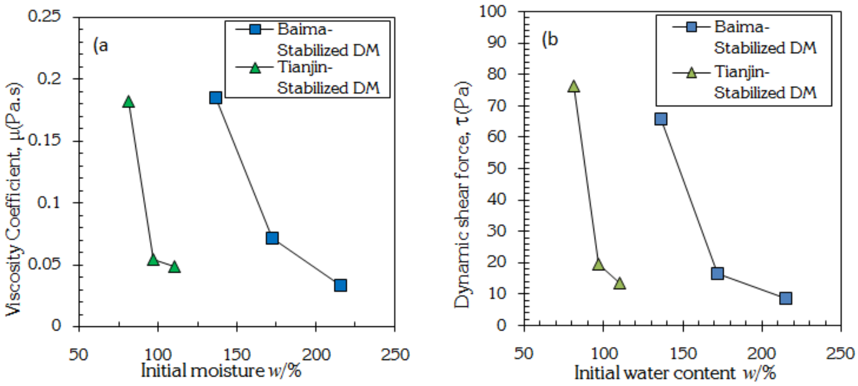

Fig.5: Variation of (a) viscosity coefficient and (b) dynamic shear force with initial water content for stabilized DMs with C150

The test results show that the rheological properties accurately reflect the flow characteristics of DM and stabilized DM. Fig. 6 shows the relationship between flow value and dynamic force for DM and stabilized DM. We can find a power function relationship can be fitted to establish a quantitative relationship between flow value F and dynamic shear force τ_0,

$$F = \alpha \cdot \tau_0^{\ \beta} \qquad (3)$$

Where *a* and *b* are fitting parameters. Table 4 lists the fitting values of *a* and *b* for Tianjin Port and Baima Lake DM, respectively. Moreover, the difference between the fitting parameters between the two DMs is very small. It shows that when treated or non-treated DM follows the Bingham fluid, the corresponding relationship between the dynamic shear force and the flow degree can be determined through the proposed equation.

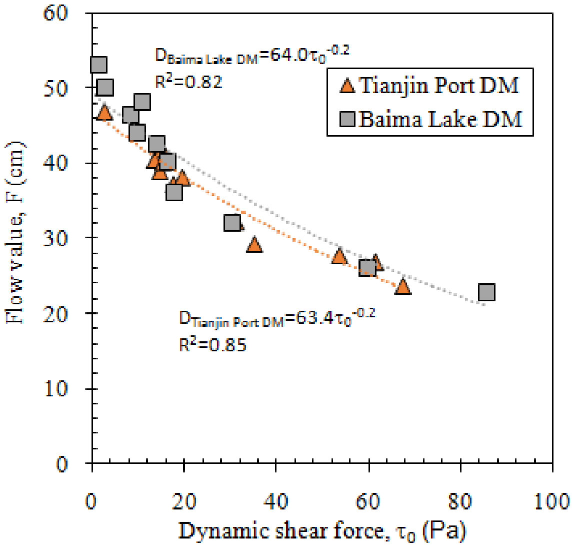

Fig.6: Variation of flow value with the dynamic shear force for different DMs or stabilized DMs

Table 4: Fitting parameters for Eq.(3)

Sources	*α*	*b*	R^2
Baima Lake DM	64.0	-0.2	0.82
Tianjin Port DM	63.4	-0.2	0.85

V. Conclusion

In this paper, a series of tests were performed to determine the rheological characteristics of cement stabilized dredged sludge obtained from two different cities located in China. The main conclusions are as follows:

(1) Flow value of the cement-stabilized DM increases with increasing initial water content; whereas, the rate of increase of flow value with respect to initial water content remains the same for all stabilized DMs. In addition, DM samples stabilized with higher cement content has lower flow value. Flow value of cement-stabilized DM should be measured in field applications such as backfill or structure fill and compared with established data or standards for improved consistency.
(2) Cemented-DMs and non-treated DMs both behaves as Bingham plastic. In addition, an ideal Bingham model is simple and good enough to describe the dredged soils. Also, in ideal Bingham model, the viscosity and yield stress are easier to be evaluated.
(3) Dynamic shear force increases significantly due to cement-stabilization. However, the dynamic shear force of stabilized DM decreases with increasing initial water content. The similar trend is observed for the viscosity coefficient.
(4) A power function relationship can be obtained between the flow value and dynamic shear force of DM.
(5) High percentages of cement should be used with caution in field applications where flow-consistency is required such as cement-soil slurry or cement-soil grout.

It is acknowledged here that the findings presented in this study are based on DM samples obtained from two locations in China, and it is expected that the general trends will be similar if different DMs are used. The results presented has improved the understanding of rheological characteristics of cement-stabilized dredged materials at high initial water content which has not been well-studied before.

Acknowledgements

The financial support from Chinese Scholarship Council (CSC) is gratefully acknowledged.

References

[1]. Bian, X., Cao, Y.-P., Wang, Z.-F., Ding, G.-Q., & Lei, G.-H. (2017). Effect of Super-Absorbent Polymer on the Undrained Shear Behavior of Cemented Dredged Clay with High Water Content. *Journal of Materials in Civil Engineering, 29*(7), 04017023. doi: 10.1061/(asce)mt.1943-5533.0001849

[2]. Chiu, C. F., Zhu, W., & Zhang, C. L. (2009). Yielding and shear behaviour of cement-treated dredged materials. *Engineering Geology, 103*(1-2), 1-12. doi: 10.1016/j.enggeo.2008.07.007

[3]. Huang, Y., Dong, C., Zhang, C., & Xu, K. (2017). A dredged material solidification treatment for fill soils in East China: A case history. *Marine Georesources & Geotechnology, 35*(6), 865-872.

[4]. Huang, Y., Zhu, W., Qian, X., Zhang, N., & Zhou, X. (2011). Change of mechanical behavior between solidified and remolded

solidified dredged materials. *Engineering Geology, 119*(3-4), 112-119.

[5]. Huang, Y. H., Dong, C., Zhan, X. L., & Guan, Y. F. (2014). Experimental Study on the Improvement of High Water Content Dredged Material by Cement and by Quicklime. *Advanced Materials Research, 878,* 714-719. doi: 10.4028/www.scientific.net/AMR.878.714

[6]. Kang, G., Tsuchida, T., & Athapaththu, A. M. R. G. (2016). Engineering behavior of cement-treated marine dredged clay during early and later stages of curing. *Engineering Geology, 209*, 163-174. doi: 10.1016/j.enggeo.2016.05.008

[7]. Kasama, K., Zen, K., & Iwataki, K. (2006). Undrained shear strength of cement-treated soils. *Soils and Foundations, 46*(2), 221-232.

[8]. Lee, F.-H., Lee, Y., Chew, S.-H., & Yong, K.-Y. (2005). Strength and modulus of marine clay-cement mixes. *Journal of geotechnical and geoenvironmental engineering, 131*(2), 178-186.

[9]. Rajendran, N. (1994). Controlled Low Strength Materials (CLSM). *Reported by ACI Committee, 229*.

[10]. Sariosseiri, F., & Muhunthan, B. (2009). Effect of cement treatment on geotechnical properties of some Washington State soils. *Engineering Geology, 104*(1-2), 119-125.

[11]. Shi, W., Chen, Q., Nimbalkar, S., & Liu, W. (2017). A new mixing technique for solidifier and dredged fill in coastal area. *Marine Georesources & Geotechnology, 35*(1), 52-61.

[12]. Soil, A. C. D.-o., & Rock. (2011). *Standard practice for classification of soils for engineering purposes (Unified Soil Classification System)*: ASTM International.

[13]. Test, M. F. (1992). Japan Highway Public Corporation Test Method. *JHS A*, 313-1992.

[14]. Thomas, D. G. (1963). Non-Newtonian suspensions-Part I: Physical properties and laminar transport characteristics. *Industrial and Engineering Chemistry, 11* (55), 18–29.

[15]. Tsuchida, T., & Tang, Y. X. (2015). Estimation of compressive strength of cement-treated marine clays with different initial water contents. *Soils and Foundations, 55*(2), 359-374. doi: 10.1016/j.sandf.2015.02.011

[16]. Wei, T. Y. L. H. Z. (2000). Study on engineering properties of cement-stabilized soil [J]. *CHINESE JOUNAL OF GEOTECHNICAL ENGINEERING, 5*, 007.

[17]. Xu, G.-Z., Gao, Y.-F., Hong, Z.-S., & Ding, J.-W. (2012). Sedimentation behavior of four dredged slurries in China. *Marine Georesources & Geotechnology, 30*(2), 143-156.

[18]. Xu, G.-Z., Gao, Y.-F., Zhang, Y., & Sun, R.-B. (2016). Rheological behavior of dredged slurries at high water contents. *Marine Georesources & Geotechnology, 35*(3), 357-364. doi: 10.1080/1064119x.2016.1173747

[19]. Xu, G., Gao, Y., Yin, J., Yang, R., & Ni, J. (2014). Compression Behavior of Dredged Slurries at High Water Contents. *Marine Georesources & Geotechnology, 33*(2), 99-108. doi: 10.1080/1064119x.2013.805287

[20]. Yu, H., Yin, J., Soleimanbeigi, A., Likos, W., & Edil, T. (2016). *Engineering properties of dredged materials stabilized with fly ash.* Paper presented at the 4th Int. Conf. on Sustainable Construction Materials and Technologies, Institution of Civil Engineers, London.

[21]. Yu, H., Yin, J., Soleimanbeigi, A., & Likos, W. J. (2017). Effects of Curing Time and Fly Ash Content on Properties of Stabilized Dredged Material. *Journal of Materials in Civil Engineering, 29*(10), 04017199.

[22]. Zentar, R., Dubois, V., & Abriak, N. E. (2008). Mechanical behaviour and environmental impacts of a test road built with marine dredged sediments. *Resources, Conservation and recycling, 52*(6), 947-954.

Shoaib Ahmed. "Rheological Characteristics of Stabilized Dredged Materials at High Water Contents." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 2, 2019, pp. 41-47