SOLIDIFICATION OF LOOSE SAND USING RICE HUSK ASH (RHA) BASED GEOPOLYMER

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ABSTRACT

Bangladesh is a densely populated country. The reclaimed marshy lands and the river banks are frequently being used to construct buildings and other infrastructures. The sub-soil of those areas mainly consists of loose sands or sand-silt mixture having low load bearing capacity, which requires ground improvement to construct sustainable infrastructures. This paper focuses on the application of Rice Husk Ash (RHA) based geopolymer as an alternate solution of ground improvement. RHA is frequently used as a waste material in Bangladesh. Therefore, the RHA activated by sodium hydroxide (NaOH) is used for soil stabilization in this study. The main purpose of this study is to determine the geotechnical properties of loose sand treated with RHA-based geopolymer to develop a cost-effective and environmentally friendly alternative ground improvement technique. The loose soil samples were collected from different reclaimed areas of Dhaka city. The physical properties as well as the engineering properties of the collected soil samples were determined by the laboratory tests. The collected soils are mixed with RHA and calcium carbonate in four different proportions. The 91%, 86%, 81%, and 76% of sand are mixed with 5%, 10%, 15% and 20% of RHA, respectively. The amount of calcium carbonate in all the mixing proportions is kept constant to 4%. The mixed soils are activated by 5M sodium hydroxide. It is observed that the alkali-activated RHA-based geopolymer can produce a considerable amount of solidification of the loose sand.

Keywords: *Ground improvement; Loose sand; Rice husk ash (RHA); Physical properties; Unconfined compressive strength (UCS).*

1. INTRODUCTION

A large portion of soils in Bangladesh is primarily composed of fluvial sediments. Besides, to meet the housing demand of the increasing population, the marshy lands in the urban and the sub-urb areas are being reclaimed with dredge sand. Therefore, there is an increasing need of soil improvement to facilitate the construction of infrastructures. The soil improvement technology is frequently employed for building infrastructure to treat the loose geological formations in coastal cities and the reclaimed urban areas. Designing a foundation in loose soil is always challenging to the Geotechnical Engineer. Consequently, the engineers are looking for an optimized solution in these conditions. There are several techniques to be used for minimizing the problematic soil condition such as sand drains, preloading, cement grouting, deep soil mixing (DSM) and chemical stabilization etc. Sand drain may lead to cavities, preloading is time consuming process and cement grouting is an expansive method. In spite of being the pilings as a historically favored engineering option, the newer deep ground improvement technologies, for example, the deep soil mixing (DSM) have been investigated for more affordable and feasible deployment. DSM is an in-situ ground treatment technology that is particularly suitable for the low to medium loaded supporting structures. It is quicker, less expensive, and more environment friendly than conventional techniques, for example, piling (Porbaha, 1998; Bouazza et al., 2004).

Chemical stabilization is another technique for minimizing the loose soil problem. The Geo-polymer-based ground stabilization is gradually being popular. A lot of studies have used Rice Husk Ash (RHA) for soil stabilization worldwide. According to Canakci et al. (2019), the addition of Rich Husk Ash (RHA) to Slag (SL) increases the reactive silica in the geo-polymerization process and creates stronger bonds in the skeletal structure of aluminosilicate compounds. The strongly bonded particles increased the compactness of the geopolymer microstructure in a dense state, which enhanced the reinforcing properties. Ali Rahman et al. (2014), found in their study that the geotechnical properties of treated residual soil may change in the presence of RHA, and it may be possible to use this material as an alternative for stabilizing the soil. Jinrong Ma et al. (2020), indicates that RHA and lime have smaller particles than other materials, they fill the space somewhat and contribute to the solidification of the soil. Mahadeva M. et al. (2017), has successfully investigated the use of silica derived from rice husk ash as a pozzolanic material in soil stabilization. Naphol Yoobanpot et al. (2014) proposed the usage of a 30% RHA as a cement substitute material to achieve a higher strength on soft soil stabilization. According to Tuhin et al. (2020), the cementitious properties of RHA increasingly effective with time. Thus, the determination of the optimum RHA concentration and the number of curing days required for gaining the desired strength is necessary.

There are a very few studies that deal with the geopolymer-based chemical stabilization of sand fills (Dredge Sand) to ameliorate marshy areas in cities and suburbs. However, loose soil, such as fine sand is a big issue for the construction of infrastructure. Furthermore, the rivers of Bangladesh are losing their navigability day by day due to the accumulation of silt flowing under the river. To ensure the navigability of the rivers, dredging has to be done every year. Consequently, a large amount of dredged soil, especially sand-silt mixture, are lifted from the riverbed. Therefore, this readily available dredged sands are commonly being used for land development of different construction areas in Bangladesh. The constructions include highway, embankments and low to medium load carrying buildings. The current study has been conducted to investigate the effect and improvement of weak subgrade in terms of compaction and strength using the waste materials such as Rice Husk Ash (RHA) along with alkaline solutions that were mixed with dredging soil (Sand). According to Noohu, N.K., and Chandrakaran, S. (2015) RHA consist of 80-90% of silica, and the silica content will be more if it is burnt under high temperature. The high percentage of silica present in the rice husk ash makes it a good soil stabilization agent. In this study, dredging sand from different locations have been collected. The collected sands were mixed with different percentage of RHA along with alkaline solution and Calcium Carbonate (CaCO3) powder to get proper solidification. The Unconfined Compressive Strength (UCS) test was conducted to investigate the strength of RHA based stabilized sample.

2. METHODOLOGY

It is already mentioned that the UCS tests have been conducted to investigate the compressive strength of the treated sample. The collected soils are compacted to achieve the maximum densification. A special compaction hammer with loading frame and compaction moulds as shown in Figure 1 have been designed to prepare the treated samples for UCS test. The weight of the hammer and the height of free fall are selected in such a way so that the compaction energy applied to the treated sample satisfies the Standard Proctor Compaction method. The weight of the designed hammer is 1000 gm, and the height of fall is selected as 23 mm. The soil samples are filled and compacted in 3 layers with 25 blows at each layer. The Unconfined Compression Test has been conducted according to ASTM D2166. It is recommended that the height of sample should be at least two to three times of its diameter. Therefore, the diameter and the height of the mould is kept 35 mm and 70 mm, respectively, having a 25 mm high collar is addition. The mould can be splitted into two parts for easily removal of the compacted soil specimen.

Figure 1: Compaction hammer with loading frame and compaction mould.

Two locations namely Biruliya and Purbachal, among many places in Dhaka city where dredging sand is available, have been selected for sand collection. The physical properties of the collected samples were tested in the geotechnical laboratory. The hydrometer and sieve analysis tests were conducted in accordance with ASTM D421-58.2012. The Specific Gravity (G_s) and Fineness Modulus (FM) tests were conducted in accordance with ASTM D854-14 and ASTM C136 respectively. Figure 2 represents the grain size distribution curve of the soil samples collected from Purbachal and Biruliya area. It is found that the gradation of the collected soil samples from two different locations were almost same as shown in Figure 2. The Purbachal is an important place because the Bangladesh government has started the land development project in that area to meet the housing demand of the densely populated Dhaka city. The construction cost in those areas will be considerably reduced if a viable RHA-based ground improvement technique can be effectively applied. Therefore, the soil samples (loose sand) have been collected from Purbachal area in Dhaka city. It was found that the sand and silt contents in the collected soils were 91% and 9% respectively. The results of the above-mentioned tests reveal that the collected soil sample was non-plastic Silty Sand. The physical properties of the collected soil samples are summarized in Table 1.

The treated samples are prepared for unconfined compression test with proper compaction. The compaction was conducted in accordance with ASTM D698-12e2. A specific amount of air-dried sands is taken which is required to fill up the mould. The air-dried sands are then properly mixed with a RHA, Calcium Carbonate ($CaCO_3$), and alkaline activator. The chemical composition of rice husk ash varies with combustion equipment, combustion temperature, combustion time and geographical location. The main chemical compound of rice husk ash is SiO2. The typical constituents of RHA according to Cook et al. (1976) are tabulated in Table 2. A 4.5-15 M range has been reported as an acceptable concentration for NaOH in terms of strength development, whereas, the 8-12 M range reported to be the most efficient (Nemalollahi and Sanjayan, 2014; Riod et al., 2017). In this study, 5.0 M sodium hydroxide (NaOH) alkaline solution is used that is prepared by using 500 ml potable water and 100gm sodium hydroxide (NaOH) pellets. Four different mix proportions of different ingredients are used in this the study. The mix proportions are described in Table 3. The percentage of calcium carbonate (CaCO3) is kept constant to 4 % in all the cases. Whereas, the percentage of RHA is changed from 5 % to 20 % as summarized in Table 3 to observe the effect of increasing amount of RHA on the solidification process of loose sand. A smaller amount of calcium carbonate is used in this study to make the ground improvement technique cost-effective.

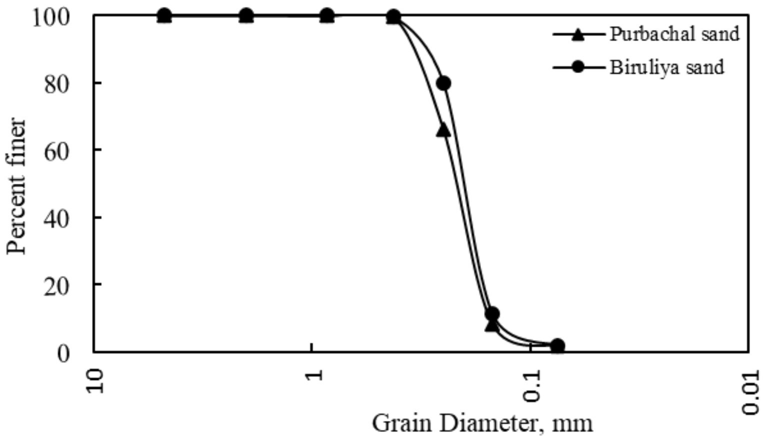

Figure 2: Gradation curve for collected sand of different locations.

Table 1 : Physical properties of collected soil.

Physical properties	Result
Specific Gravity (G_s)	2.65
Maximum Dry Density (kg/m^3)	1531.69
Optimum Moisture Content (%)	16.02
USCS classification	SM
FM	1.09

Table 2: Constituents of RHA (Cook et al. (1976)).

Ingredients	Amount (%)
SiO_2	93.15
Al_2O_3	0.41
Fe_2O_3	0.20
CaO	0.41
MgO	0.45
K_2O	2.31
Na_2O	0.08

Table 3: Mix proportions of the ingredients.

Mixture Name	Sand (%)	RHA (%)	$CaCO_3$ (%)	5 Molar NaOH Solution based on OMC (%)	Curing Time (day)
P5M5	91	5	4	18.82	7
P10M5	86	10	4	20.88	7
P15M5	81	15	4	22.93	7
P20M5	76	20	4	24.10	7

The mixtures are placed into a splitted mould made of aluminum in three layers to prepare cylindrical specimens having the dimensions of 35 mm in diameter and 70 mm in height. Each layer is tapped with 25 blows by a properly maintained height of fall by using the designed compaction hammer to achieve maximum densification. The treated sample is taken out from the compaction hammer. Then the prepared samples are taken out of the aluminum mould by using a mechanical ejector and are kept in the room temperature for curing. Three samples were prepared for each mix proportion & cured for 7 days to ensure the consistency of the test results. To assess the performance of stabilized samples, unconfined compressive strengths (UCS) of all samples were conducted. After the specified curing period, the sample has been kept on the bottom plate of unconfined compression machine & fixed it with the above plate for proper contact. Then, the displacement dial gauge & the load dial gauge have been adjusted to zero. The Unconfined Compression strength (UCS) tests were conducted at a rate with 0.7 mm/min of axial deformation (1% strain per minute) and stopped manually after the specimens reached a satisfactory post-peak strength loss.

3. RESULT AND DISCUSSION

Unconfined compressive strength (UCS) is the most common and adaptable method of evaluating the strength of soil. This test is recommended for the determination of the required amount of additive to be used in stabilization of soil (Singh and Singh, 1991). The test is conducted accordance with-ASTM D 2166-00. 2012.

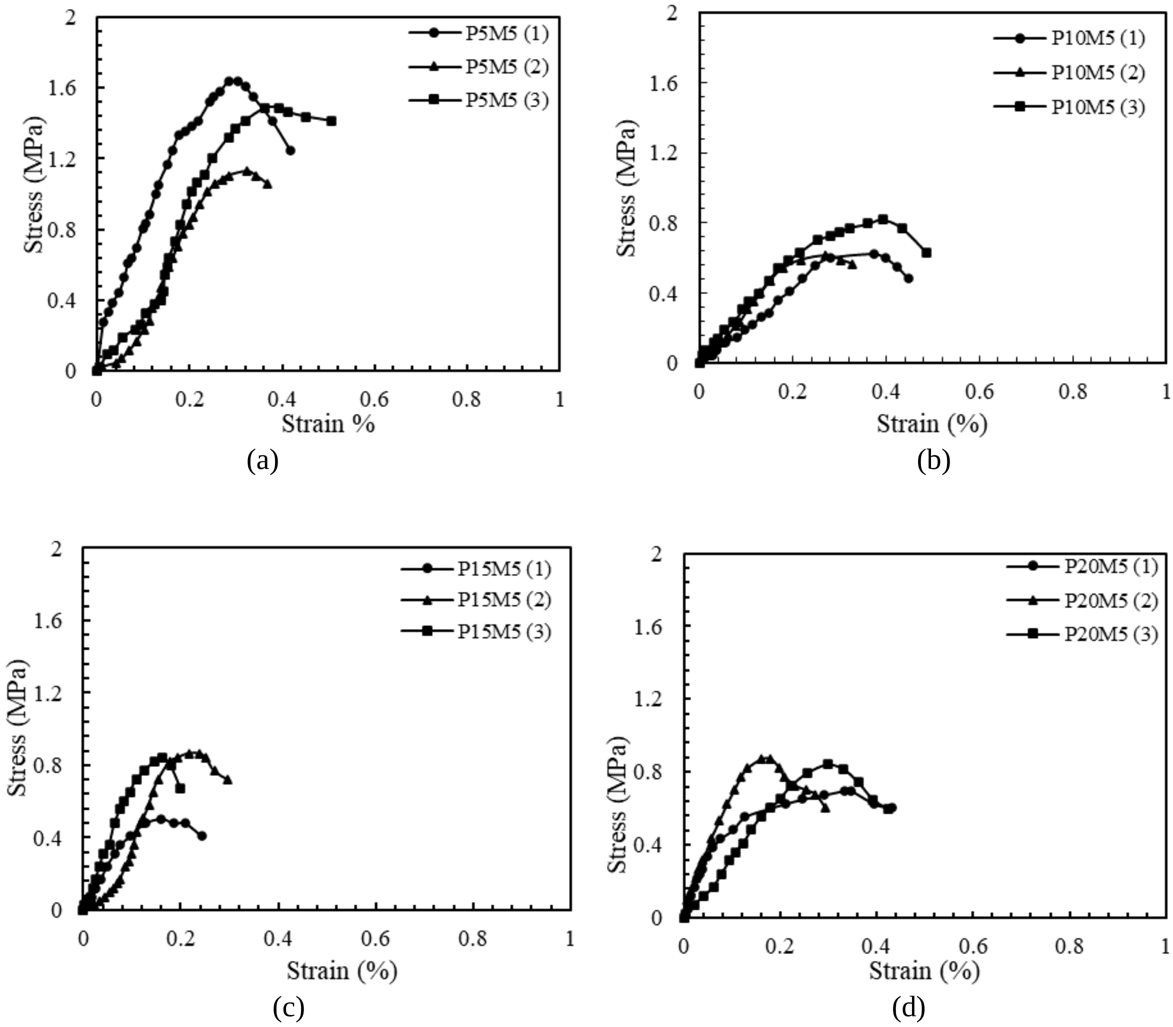

Figure 3: Stress Vs Strain curve at 7 days curing for different percentage of RHA content; (a) for P5M5, (b) for P10M5, (c) for P15M5, (d) for P20M5.

Figure 3(a), 3(b), 3(c) and 3(d) represent the stress-strain curve of the treated samples (after 7 days curing) for the mixture of P5M5, P10M5, P15M5 and P20M5, respectively. The UCS test was conducted for three prepared samples of each mixture. The obtained stress- strain result is plotted in each respective graph. The mixing proportion of different materials for exaple collected sand, RHA, $CaCO_3$ and the molarity of alkali activator for P5M5, P10M5, P15M5 and P20M5 are summarized in Table 3. The failure pattern of the 4 different samples after UCS test are shown in Figure 4(a) to 4(d). From the stress strain graph and the failure pattern it is observed the failure of the stabilized sample is brittle in nature in all the cases.

(a) (b) (c) (d)

Figure 4: Failure Pattern of RHA based stabilized speciman after 7 days of curing; (a) for P5M5, (b) for P10M5, (c) for P15M5, (d) for P20M5.

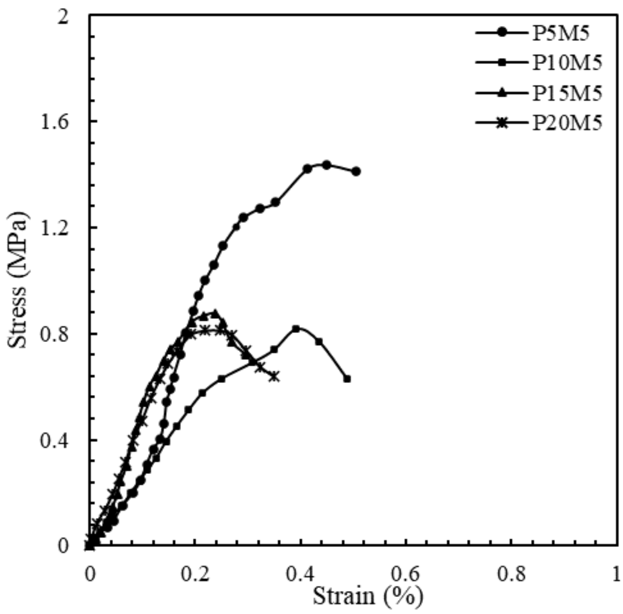

Figure 5: Stress Vs Strain curve for different percentage of RHA.

Table 4: Dry density and UCS Test Result.

Percentage of rice husk ash (%)	Dry Density (kN/m^3)	Maximum UCS (MPa)
5	16.87	1.44
10	14.91	0.82
15	14.81	0.88
20	14.42	0.81

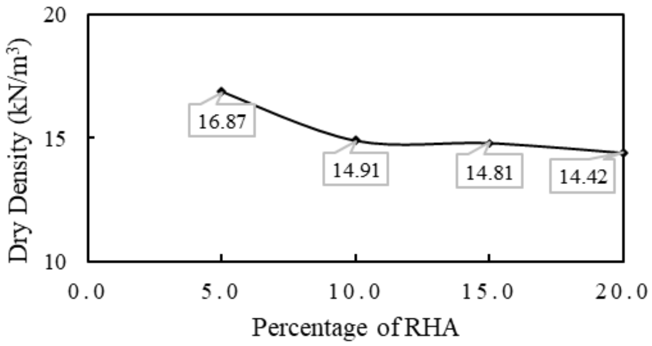

Figure 6: Variation of dry density with different percentage RHA content.

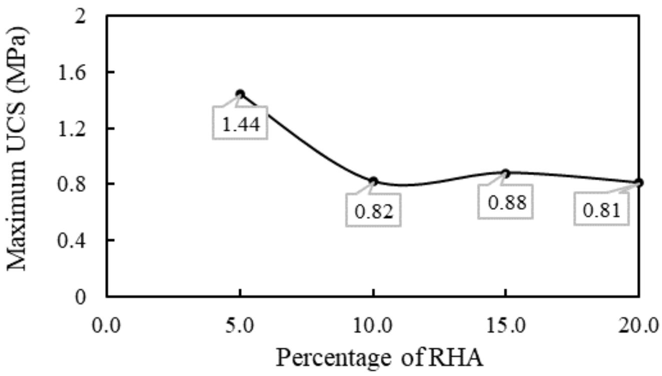

Figure 7: Variation of average maximum unconfined compressive strength with different percentage RHA content.

The average stress and strain vaues were determine from the three tested samples in each mixture group. The average stress strain curve for 4 different mixture group shown in Figure 5. The maximum unconfined compressive strength for 4 different samples are summarized in Table 4. Figure 6 represents the variation of the dry density of the treated samples with the percentage of the added RHA. The graph shows that the maximum dry density of the stabilized samples is obtained in the case of P5M5 where the RHA content is 5%. After that the dry density decreases with the increased percentage of RHA. Similarly, the average maximum unconfined compressive strength of the treated samples are plotted against the percentage of the added RHA as shown in Figure 7. The graph shows that the maximum unconfined compressive strength is also observed in the case of P5M5 following a gradual decrease in the case of P10M5, P15M5 and P20M5.

The unconfined compressive strength of the treated soil depends on the pozzolanic reaction of RHA along with the particle packing of fine sand. Usually, the internal voids between the sand particles are filled up with the fine RHA particles during the compaction process which enhances the soil densification. Simultaneously, the pozzolanic reaction of RHA with alkaline solution creates the bonding between the soil particles. However, the excess amount of RHA which is not required to fill up the voids imposes additional volume thus reduces the density of the treated sample. At the same time, it reduces the particle to particle contact of the sand grains. The maximum densification of the treated samples is observed in P5M5 mixture. The density at P5M5 mixture is approximately 16.87 kN/m^3 which is almost 17% higher than the minimum density of 14.42 kN/m^3 at P20M5 mixture as shown in Table 4. Similarly, the maximum unconfined compressive strength was obtained as 1.44 MPa in the same mixture of P5M5 (at 5% RHA content) after 7 days of curing. The strength is observed to decrease gradually with the increases in the percentage of RHA which is probably due to the lesser densification and smaller particle to particle contact in the treated sample. It is evedient from the experimental results that the densification of the fine sand plays an important role in the ground solidification techniques using RHA-based geopolymer.

4. CONCLUSIONS

The soil samples collected from Purbachal area were mixed with different percentage of RHA, alkaline activator and $CaCO_3$. The UCS test were conducted to observed the efficiency of the solidification of loose sand usinng RHA-based geopolymer. It is observed that the alkali-activated RHA-based geopolymer can produce a considerable amount of solidification of the loose sand. The following conclusion can be drawn from the test resuts:

(a) The maximum dry density is obtained for the RHA content of 5% in this particular sand. The dry density is further decresed with the addition of RHA.
(b) Similarly, the maximum unconfined compressive strength is obtained for the RHA content of 5%.
(c) Particle packing density plays an important role in the solidification of loose sand.

ACKNOWLEDGEMENTS

The financial support of this study was provided by Housing and Building Research Institute (HBRI), Dhaka, Bangladesh. The Authors would like to express their gratitude to lab technician of Geotechnical Engineering Laboratory of HBRI for their continuous support.

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