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USE OF DRY MIXING METHOD IN FLY ASH BASED GEOPOLYMER AS A STABILIZER FOR DREDGED SOIL

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ABSTRACT: This study aims to improve the properties of dredged soil obtained from a river in the Philippines. Different percentages of fly-ash based geopolymer, namely 10%, 20%, 30% were used using a dry mixing method to determine the optimum mix. The procedures based on the ASTM standards were conducted to determine the index properties namely Grain Size Distribution Curve (ASTM D422), Specific Gravity (ASTM D854), Atterberg's Limits (D4318), and CBR Test (ASTM D1833) and UCS test (ASTM D2166) of untreated soil. While only the California Bearing Ratio Test and UCS test were conducted on the treated soil. The experimental results showed that the fly-ash based geopolymer improved both the CBR index and the Unconfined Compression Strength of the dredged soil. The optimum mix for the soil-geopolymer mix was 30% because it displayed the largest increase in the CBR index (50.23%) and Unconfined Compressive Strength (912.88 Kpa).

Keywords: Fly ash, Geopolymer, Soil stabilization, California bearing ratio, Unconfined compressive strength

1. INTRODUCTION

Soil stabilization is an engineering process which is used to modify and improve the properties of the natural soil. The main objective of soil stabilization is to increase its soil strength and stability. Other soil properties like its durability, permeability and bearing capacity must also be considered in order to achieve the required soil specifications for construction applications. This process can be applied to the construction of roads, pavements, embankments, and other uses. Two processes of soil stabilization include mechanical stabilization and chemical stabilization. Chemical stabilization is subjected to chemical reactions of the stabilizer and the minerals of the soil. Based on previous studies, cement, lime, bitumen and fly ash are the commonly used stabilizing agents that utilize the industrial wastes and natural resources [1].

The use of dredged material as a resource has broad social, environmental, and financial benefits, thus, contributes to global sustainability. Its two broad categories of uses are engineering uses and environmental uses and the utilization of the dredged soil for beneficial uses may be considered as an environmentally friendly and economical option. In order to achieve this goal, chemical admixtures are to be added to the dredged material so that its properties are modified. Past studies have been attempted to modify dredged material as the fill materials, for instance, the use of blast furnace slag cement and quicklime as additives to modify the dredged material as the embankment fill [2].

Geopolymer is synthesized through a mixture of aluminosilicate raw material from industrial wastes such as blast furnace slag, silica fume, fly ash or bottom ash and an alkali activator. Through this synthesis, a structured polymer is created forming a series of sialate monomers that have similar properties to cement. Fly-ash based geopolymers have already been studied as an alternative for cement that has shown an increase in compressive strength, resistance to acid and low shrinkage. With the reduction of carbon dioxide in the production of a cementitious material through geopolymer, the study aims to create an effective geopolymer mix that will stabilize the dredged soil. Thus for this study, a geopolymer based on fly ash will be used to modify and improve the geotechnical properties of dredged soil that will be obtained from a river beside a coal-fired power plant in Mindanao. Numerous studies have shown that coal combustion by-products, or more commonly known as CCPs, have been found to be a good choice because it is very abundant in the country and has a problem in disposal [3-10]. The tests that will be conducted in the study are the Standard Proctor test, CBR and Unconfined Compression Test [11-13].

The primary objective of the study is to investigate the effects of using dry mixing method of fly ash based geopolymer as a stabilizer to improve on the geotechnical properties of dredged soil. Moreover, the study aims to incorporate the soil stabilization process by performing tests on the untreated soil and at the same time evaluate the increase on the shear strength and load-bearing capacity. Lastly is to determine the application of the various mixture proportions of dredged soil and geopolymer.

2. METHODOLOGY

Tests in accordance with the ASTM standards are utilized on the dredged soil sample to determine the effect of using the dry-mixing method in fly ash based geopolymer as a stabilizing agent on the untreated soil.

In this study, the soil that was dredged from a heavily silted river beside the coal-fired power plant in Mindanao was used as the soil specimen. The properties and characterizations of the dredged material were obtained by conducting several test procedures. The determination of its water content and its optimum moisture content are its prime importance.

Dry alkaline activators which are the sodium silicate and sodium hydroxide were utilized in this study. Sodium silicate is a common name for sodium metasilicate and its term is also known as a water glass solution. This can be both in solid and in liquid form, thus, it is constant in both neutral and alkaline solution. Sodium silicate alone is not advisable to be used as an alkaline activator since it does not possess enough potential to initiate pozzolanic reaction independently. Thus, it is commonly mixed with Sodium hydroxide as an assisting agent to improve the overall strength of the specimen. Sodium hydroxide, NaOH, is an organic compound and is also known as caustic soda. It is described as a white solid with a highly caustic metallic base and alkali salt. It can be in powdered form or any granular or flakey material. It is a commonly used activator for geopolymerization and it can be combined with sodium silicate for the production of geopolymer paste.

The study involved experimental procedures in the laboratory including its soil characterization tests, design mix, soil-geopolymer mix, soil-cement mix, curing of the specimen, testing of the strength of the soil stabilized with geopolymer and analysis of results.

Before the specimens were prepared, the geopolymer paste was prepared first prior to mixing with the dredged soil. The formulation of the geopolymer mix was already determined. Sodium Hydroxide and Sodium Silicate were mixed in the mixer, then fly-ash was placed with the mixture after the activators were thoroughly mixed. Water was then added and mixed for 10 minutes, to which produced the geopolymer paste. The mix of dry and wet ingredients varies on the percentage of geopolymer to the soil.

Specimens of dredged soil at optimum moisture content were mixed with geopolymer stabilizer. The dredged soil with geopolymer stabilizer (DSGS) was rammed in the California bearing ratio mold that obtained a compacted density ranging from 95% to 100% with 54 blows each for 5 layers. Specimens were to be taken for its moisture content from the top and bottom of the mold then recorded measurements obtained from the mold and compacted specimen. Specimens were then tested under the Uniframe after 7 days of unsoaked and ambient condition. Values of the penetration load were then collected and used to obtain the load-penetration curve and bearing ratio.

Test specimens are about 40 mm in diameter and 100 mm in height and are compacted for the unconfined compression test following the ASTM D 559. The soil- geopolymer mix was compacted in a cylindrical PVC mold with 25 blows each for 3 layers and was kept in humid conditions for 28 days. After the curing period, the test specimens were then placed in the loading device. The load was applied so as to produce an axial strain at a rate of 1⁄2 to 2% per minute. The machine provided the load, deformation, and time values at sufficient intervals and was recorded to obtain the value of the unconfined compressive strength of soil-geopolymer, as well as the soil-cement, and the shape of the stress-strain curve.

The chemical composition of the fly ash sample and characterization of the stabilized soil was obtained through Scanning Electron Microscopy-Energy Dispersive X-Ray Analyzer (SEM-EDX), that provided in-depth microstructure analysis. Samples underwent high-resolution imaging and obtained the information of elemental composition as well as the lateral dimensions particles through SEM-EDX.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength of Pure Geopolymer Past

A compressive strength test was conducted on the pure geopolymer paste using the two different fly ash that was given by the power plant. The difference with the two types of fly ash was that Fly Ash 1 (FA1) did not undergo desulfurization in the production of power, however, Fly Ash 2 (FA2) undergone desulfurization in its production of power. The geopolymer paste consisted of 0% soil and 100% geopolymer using the dry mix method. Table 1 shows that it garnered an average compressive strength of 10.46MPa, while at Table 2 shows that it only reached a strength of 2.2MPa.

Table 1. Compressive Strength of FA1 (Without Desulfurization)

Area (mm^2)	F (N)	Strength (MPa)
2,451.28	31,100	12.69
2,450.91	31,600	8.81
2,429.08	34,000	9.88
	Average	10.46

Table 2. Compressive Strength of FA2 (With Desulfurization)

Area (mm2)	F (N)	Strength (MPa)
2,409.70	5,400	2.24
2,437.65	4,800	1.98
2,353.70	4,300	1.83
	Average	2.20

3.2 Characterization of Geotechnical Properties of Dredged Material

The basic physical characterization of the pure dredged soil such as the specific gravity, particle size analysis, atterberg limits and standard Proctor test were examined to obtain its geotechnical properties. More so, based on the Unified Soil Classification System (USCS) and AASHTO, the dredged soil was classified as Poorly Graded Sand (SP) and Fine Sand (A-3) respectively. The untreated soil was oven-dried prior to testing to attain consistent results, following the ASTM procedures and thus, Table 3 shows the garnered results from the three trials that were conducted per test.

Table 3. Geotechnical Properties of Dredged Soil

Description	Value
Specific Gravity, Gs	2.66
Liquid Limit, LL	None
Plasticity Index, PI	NP
Optimum Moisture Content (OMC, %)	17.59
Max Dry Unit Weight (KN/m3)	17.23
Unsoaked CBR (%)	1.19

3.3 Strength Tests

It can be observed that there was a significant increase in the CBR strength when the geopolymer was introduced to the dredged soil. It was shown that for a 10% geopolymer concentration, a minimum value of 8.57 was generated and a general rating of fair for subbase was obtained. A general rating of good for base and subbase course resulted for the 20% replacement while a general rating of excellent for the base course was obtained for the replacement of 30% geopolymer on the dredged soil.

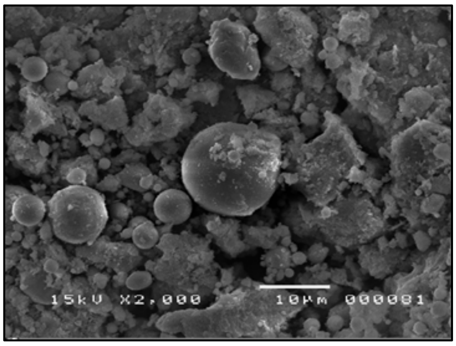
The increase in the CBR Index follows a polynomial trend. The polynomial correlation was chosen to demonstrate the relationship between the percentages and the CBR Index since it resulted in the greatest regression value.

It shows that a pure dredged soil is not capable of performing unconfined compressive strength test alone, but blending geopolymer with the soil allowed to produce confinement as little as 10%, following a series of 20% and 30%. When the soil was mixed with a geopolymer concentration of 10%, the value of the gained strength of 100.94 kPa belonged to typical strength of stiff soil (100-200 KPa). As the geopolymer concentration increased to 20%, the gained strength value of 157 kPa still belonged to the typical strength of stiff soil (100-200 KPa). A significant increase can be observed when the soil was mixed with a geopolymer concentration of 30% since the grained strength of about 912.88 KPa belonged to the typical strength of hard soil (>400 KPa).

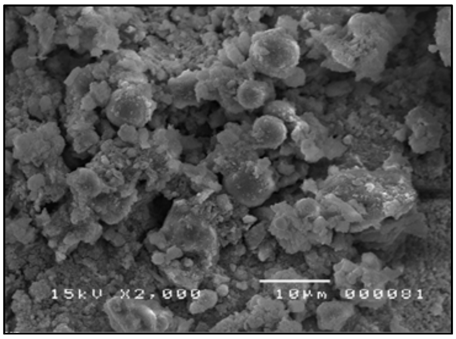
The statistical analysis of the Unconfined Compression Strength test results indicated that an exponential relationship can be developed between the varying geopolymer concentration and its average UCS values. It can be seen that as the percentage of geopolymer increases, the UCS values also tend to increase and vice versa. This relationship was chosen as the best measure since the regression value (R2) resulted close to 1.

3.4 Morphological Analysis

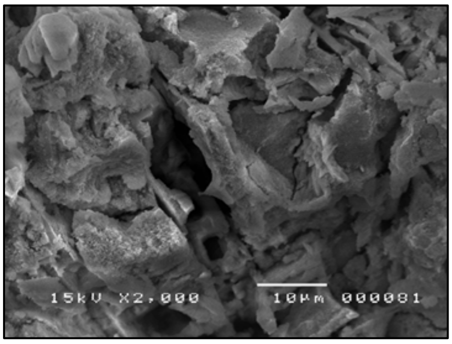
Since most of soils properties such as unit weight and strength are attributed to its microstructure. Scanning Electron Microscope (SEM) was conducted on the soil-geopolymer mix to clearly visualize the particle angularity, assemblage and surface texture. Figures show the SEM microphotographs of the 10% 20% and 30% geopolymer mix, shown in Figure 1. It was found that the spherical particles, which represents fly ash gradually decrease as more geopolymer percentage was added on the soil.



(top)



(middle)



(bottom)

Fig.1. SEM photomicrographs of 10% (top), 20%(middle) and 30%(bottom) geopolymer mix at 2000x

There were no more spherical objects and more of the white particles had appeared even forming crystalline-like structures. This indicates that the geopolymer had fully formed. As the percent of the geopolymer was increased the presence of the geopolymer had become more evident. This would explain why the 30 % geopolymer mix had the largest increase in strength. Since the formation of the geopolymer was more extensive compared to the other mixes.

4. CONCLUSIONS

The load-bearing capacity of the dredged soil stabilized with geopolymer through dry mixing method showed that there is an increase in the strength behavior of the sample. The dry mixing method was able to improve the geotechnical properties of the dredged soil, but at the same time, it is practical to use on site. The strength of the geopolymer improved with time because of its cementitious reaction. However, excess alkali activator resulted as there is an increase of geopolymer to the sample, still, results showed an exponential increase. The replacement of 30% geopolymer on the dredged soil resulted to be best used for Base course with a general rating of excellent, according to the Philippines' Department of Public Works and Highways (DPWH) Standard. The 20% replacement of geopolymer to the dredged soil resulted to a general rating of fair for Base and Subbase course and the 10% replacement of geopolymer to the dredged soil was only rated good as a subbase course.

The dredged soil ran through a series of geotechnical tests, and it was classified as a poorly graded sand. The dredged soil moisture-density relationship resulted to values of (OMC) and max dry density (MDD) within the range of Poorly Graded Sand which was (12% - 21%) and (15.71 $KN/m3$- 18.85 $KN/m3$). Additionally, the unconfined compressive strength test on the dredged soil produced an invalid strength, due to its dry and crumbly characteristics that was not suitable for the strength test.

The CBR value of 1.19 resulted for the dredged soil alone. However, with the variation of mixes of 10%, 20%, and 30%, it was found that CBR index values increased with the further increase of geopolymer added to the dredged soil. The maximum CBR value was obtained at 30% geopolymer replacement on the soil, at a CBR value of 51.33%. The minimum CBR value was obtained at 10%, with a CBR value of 8.57. The improvement of the dredged soil when replaced with geopolymer it increased by 3.21 – 19.22 times the base CBR value of the dredged soil alone.

More so through the unconfined compressive strength of the stabilized dredged soil had an increasing trend as the mixed ration of geopolymer increased. The 10% replaced geopolymer gained a strength value that is classified as the strength of medium soil at 100.94kPa. The 20% and 30% replaced geopolymer gained a strength value that is classified as the strength of stiff at 157.0kPa and strength of hard soil at 912.88kPa, respectively. It is evident that the unstabilized dredged soil, on the other hand, showed a significant improvement, due to the fact that sample was too loose to stand by itself, to begin with; it had no coherent value.

Previous studies have not performed the California Bearing Ratio test for soils that are to be stabilized with geopolymer; although, statistical analyses are provided on the latter part of this chapter. Comparing the results of the CBR test with the results of the UCS test, it was observed that the behavior of the increase in CBR value of the three geopolymer concentrations is similar with the behavior of the increase in strength for the unconfined compression strength test results.

Based on the physicochemical characteristics of the fly ash that was used for geopolymerization, it was found that toxic heavy metals were at the permissible limit or not detected according to the TCLP standards. Thus, the fly ash can be categorized as non-hazardous based on regulatory leaching test. Furthermore, the mineralogical and elemental indicated that there is a presence of reactive alumina and silica that is a suitable raw material for geopolymerization.

The use of a dry mixing method of fly ash based geopolymer as a stabilizer of dredged soil has a decrease in terms of cost in stabilization in the alternative to cement. More so given that the materials of fly ash are by-products of the industry and dredged material have less significant use, the study was able to be of use for such materials.

5. RECOMMENDATIONS

Due to time constraint and limited resources, both the fly ash and dredged soil come from only one coal-fired power plant source was used. However, it is recommended to use samples from other power plants and dredged soil across the country for verification of the results in order to avoid the geographic limitation on its widespread use. Moreover, only the CBR (ASTM D1822) [14] and unconfined compression test (ASTM D2166) [15] were conducted on the treated soil. Furthermore, other tests such as particle size analysis (ASTM D422) [16], specific gravity (ASTM D854) [17], Atterberg's limit (ASTM D4318) [18], standard Proctor test (ASTM D698) [19] to be conducted to on the treated soil to determine its effect on the geotechnical other properties.

Moreover, from that additional test for different curing periods such as 7 days, 14 days and 28 days for both the CBR and UCS test this is to observe the behavior of the increase in strength of the soil and geopolymer mix. It is also highly recommended to wear protective gloves in mixing geopolymer to avoid skin infection.

Lastly, aside from strength, other factors such as draining should be considered when dealing with road embankments. That is why the researchers would also recommend conducting a permeability test (ASTM D2434) to determine the hydraulic conductivity of both the untreated and treated soil. This would determine its suitability to be used in road embankments.

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