STRENGTH PROPERTIES OF CHEMICALLY STABILIZED ROAD SUBBASE MATERIALS WITH LIME SLUDGE AND FLY ASH

Vera Karla S. Caingles, Eddie Bergonia, Jeffrey Ken B. Balangao, Israel A. Baguhin
College of Engineering and Architecture, University of Science and Technology of Southern Philippines, Cagayan de Oro City, Philippines
Email: vera.karla@ustp.edu.ph

***ABSTRACT**: Current chemical stabilizing practices involve using cement, lime, bitumen and other chemical stabilizers that are expensive because of its reliance on the use of manufactured chemicals. The purpose of this research is to assess the geotechnical properties of subbase materials when the industrial waste fly ash (FA) and lime sludge (LS) are used as stabilizers for road subbase coarse materials. This quantitative research considered five soil samples that were treated with FA contents of 10%, 20%, 30%, 40%, and 50% in addition to the constant LS and cement contents of 10% and 1% respectively. The untreated and treated soil samples were tested to identify the physical and index properties of subbase materials, compaction behavior, and California Bearing Ratio (CBR) of the samples. Results showed that the soil strength (CBR) tended to increase when FA content is increased. Moreover, the highest value of soil strength is obtained when the soil is mixed with 50% FA, 10% LS, and 1% cement contents. Therefore, it was concluded that the admixture of FA, LS, and Cement is a potential chemical stabilizer for road subbase coarse materials. Moreover, further study on increasing the FA content beyond 50% to the admixture is recommended.*

Keywords: chemical stabilization, cement, lime sludge, fly ash, sub base

1. INTRODUCTION

Civil engineering structures are founded in or on the surface of the earth. Soil serves as the ultimate foundation for all structures, thus, its geotechnical properties will greatly contribute to the stability of these structures. In designing a pavement, success does not solely depend on the quality of the top layer, such as the concrete pavement or asphalt, but also on the underneath layers like base, subbase, and subgrade [1].

Subbases/bases are usually constructed materials out of smaller rocks of various shapes and fragments that often have holes or gaps and can be compacted to create a hard surface. They act as structural layers that help in spreading the wheel load before it transmits to the subgrade thus, the subgrade layer will not be over-stressed [2]. Improving the geotechnical properties of these pavement layers, through stabilization, is significantly important to save resourceful construction materials. Hence, well-stabilized soil is vital for the appropriate purpose and proper function of the structures.

Soil stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for construction beyond their original classification [3]. It improves soil properties and transforms unsuitable soil into the required condition. More so, it increases bearing capacity or reduces settlement, water permeability, or risk of liquefaction [4].

The stabilization process is divided into two broad fields namely; mechanical and chemical stabilization. Mechanical stabilization requires compaction, aggregate mixing, gradient improvement, and asphalt cement extension. Chemical stabilization requires the mixing of chemicals to the soil like cement, lime, asphalt, or fly ash. The most common chemicals adopted for soil treatment are cement and lime [5]. However, the construction cost of soil stabilization using the latter chemicals is remained financially high because of the over-dependence on the use of manufactured additives that strengthen the soil.

Various engineering studies have revealed the possible replacement of cement and lime in soil stabilization by exploring the effectiveness of using industrial wastes as stabilizers. These include by-products from paper milling and sugar milling companies known as lime sludge [6-9] and hyposludge [10], a by-product from rice milling company known as rice husk ash [11], from coal-fired thermal power plant called fly ash [12-16] among others.

The municipality of Villanueva in Northern Mindanao, Philippines has a coal-fired power plant. The fly ash generated by the plant is currently utilized by the host town as an admixture to cement to manufacture construction materials such as concrete hollow blocks (CHBs), bricks, and pavers. However, the mechanical and environmental properties of these construction materials were not determined. With the continuous generation of fly ash at the plant, the best option for reducing it is to utilize it for construction purposes such as in those of other agro-industrial wastes [6-20]. Consisting of predominantly spherically-shaped particles [21-23], fly ash contains heavy metals [24-25] which make it hazardous. Therefore, there should be no environmental problems with any construction materials with fly ash in order for them to be safe to use. One possible way to immobilize the heavy metals in the fly ash in the mix is through the addition of other pozzolanic and cementitious resources.

The idea of coming up with a study of adding lime sludge with the fly ash to further stabilize soil was considered when [8] was able to utilize it in the stabilization of clay. The said lime sludge is produced by a sugar milling plant in Bukidnon, Philippines, and is currently not utilized and properly disposed, thereby, piling it in an open dump. According to the study, major proportions of lime sludge such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and calcium oxide (CaO) were the same as major components found in the Portland cement. Results of their study revealed that the addition of 10% by weight of lime sludge increases the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of the said clay as subgrade soil.

The combination of fly ash and lime sludge to replace cement and lime to stabilize the base/subbase layer of road pavement is promising; just like any other resource combinations processed for a specific application [9-10, 17-19, 26-28]. The combination is likely to reduce the time and costs of production for cement and lime, preventing harmful gases to be emitted from their manufacture. It allows saving natural land resources [29] which are to be used in manufacturing them and promotes sustainability in the production since it actually utilizes wastes which are generated daily from their sources.

This work intended to evaluate the potential application of fly ash and lime sludge as stabilizing agents to improve the properties of a road subbase material. Basically, this study focused on determining the mixture of soil and lime sludge-fly ash-cement with respect to its curing period that has attained the highest value of California Bearing Ratio (CBR) of soil intended as subbase material. The untreated and treated soil samples were identified as the input parameters. The process was mainly laboratory testing of the untreated and treated soil samples. Lastly, for the expected output, the untreated samples acted as the control group which become the basis in evaluating the results if there are significant improvements on the geotechnical properties of soil as it is being treated with lime sludge (LS), fly ash (FA), and Ordinary Portland Cement (OPC).

2. MATERIALS AND METHODS

2.1. Selection of Site for Soil Sampling

Locally available sources of subbase course soils were randomly picked as suggested by the Department of Public Works and Highways (DPWH) of the Philippines. There were no particular parameters set on the selection of soil sample for this study because most of the time in the actual construction, the material used for this pavement layer is being blended and modified to meet DPWH standards.

2.2. Collection and Preparation of Soil Sample

In this stage, soil sample was hauled from the site and placed in a suitable container to preserve moisture. The soil sample was carefully stored in a container and underwent various physical, index, and mechanical tests in accordance with the American Society of Testing and Material (ASTM) standards. The tests included sieve analysis (ASTM D6913: Standard Test Methods for Particle-Size Distribution of Soils Using Sieve Analysis), specific gravity (ASTM D854: Standard Test Methods for Specific Gravity of Soil Solids by water Pycnometer), Atterberg limits (ASTM D4318: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils), compaction test (ASTM D1557: Standard Test Methods for Laboratory Compaction Characteristics of Soil using Modified Effort), and CBR test (ASTM D1883: Standard Test Method for CBR of Laboratory-Compacted Soils). The obtained values of Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) from compaction test were used for the CBR test. As to the curing process, for CBR test, the soil sample was soaked in a curing tank with water for 4 days before being penetrated by the CBR machine. The amount of water for CBR test was computed using formula based on the volume-density relationship as given in Equation 1. The hydroscopic moisture content (HMC) is the in-situ moisture content of the soil which was obtained by oven-drying the soil samples for 24 hours at 100+10ºC. The OMC is the moisture content at which the maximum dry density is obtained in the compaction test.

$$Weight\ of\ Water = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\right) x \left(\frac{OMC-HMC}{100}\right) \quad \text{Eq. 1}$$

2.3. Collection and Preparation of Lime Sludge, Fly Ash, and Cement

Lime sludge was collected from a sugar milling company in Bukidnon, Philippines. The coal fly ash was taken from a coal power plant in Villanueva, Misamis Oriental, Philippines. Both the lime sludge and fly ash were air-dried to be easily pounded to finer grains. Sieving of the raw materials using sieve no. 200 was done. More so, the loss on ignition (LOI) test was performed before these materials were mixed to the cement and soil to ensure that the grain particles of lime sludge and fly ash are as fine as the cement. Type 1 portland cement available in the market was used. The cement was sieved using no. 200 before mixing with soil, lime sludge, fly ash, and water. The soil samples were thoroughly mixed until a uniform color is observed.

2.4. Preparation of Blended Sample

The variation of the mixtures was based on the minimum standard set by the DPWH and best percentage suggested by previous studies. Variation of mixes is presented in Table 1. As stipulated in the DPWH Blue Book (2013), the amount of cement to be added to the soil-aggregate shall be from 6 – 10 mass percent of the dry soil. Hence, in this study, the maximum amount of cement added was within 1% for the sets of mixture. The percentage addition of fly ash ranged from 10% to 50% by soil dry weight with an interval of 10%. Meanwhile, for the lime sludge, the percentage addition by soil dry weigh was 10% to sets of mixture.

Table 1. Variation of Mixtures

Soil Samples	Aggregate Base/Subbase Course	(% OPC + %LS + %OPC)
A	100% Soil	1%OPC + 10%LS
B	100% Soil	1%OPC + 10%LS + 10% FA
C	100% Soil	1%OPC + 10%LS + 20% FA
D	100% Soil	1%OPC + 10%LS + 30% FA
E	100% Soil	1%OPC + 10%LS + 40% FA
F	100% Soil	1%OPC + 10%LS + 50% FA

After attaining the required amount of soil aggregate, lime sludge, fly ash, and OPC in each soil sample, itwas then tested for compaction and CBR to evaluate its properties as subbase material. Similar curing procedures were adopted for the treated soil. For CBR test, the amount of water was computed using formula using the volume-density relationship as shown in Equation 2. Meanwhile, Equations 3 – 5 were used to determine the weight of stabilizers in each soil sample, respectively.

$$Weight\ of\ Water = \left[\left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\right) + Weight\ of\ LSA + Weight\ of\ FA + Weight\ of\ OPC\right] x \left(\frac{OMC-HMC}{100}\right) \quad \text{Eq. 2}$$

$$Weight\ of\ LSA = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\ x\ Percentage\ of\ LSA \right)$$
Eq. 3

$$Weight\ of\ FA = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\ x\ Percentage\ of\ FA \right)$$
Eq. 4

$$Weight\ of\ OPC = \left(\frac{Weight\ of\ soil}{1+\frac{HMC}{100}}\ x\ Percentage\ of\ OPC \right)$$
Eq. 5

3. RESULTS AND DISCUSSION

3.1. Physical and Index Properties of the Subbase Material

The sieve analysis revealed that the soil sample consisted of 0% gravel or soil particles with more than 2mm size, 91% sand or soil particles with sizes ranging from 2mm to 0.075mm, and 9% silt and clay or soil particles with less than 0.075mm size. This means the soil samples contain dominantly sand with very little of clay. Moreover, the grading criteria of passed the DPWH requirement for subbase material. Based on the Atterberg limit values, the liquid limit and plastic limit of the soil were 26% and 0%, respectively. This indicates that soil exhibited non-plasticity properties. Non-plastic soil is a non-cohesive soil that does not bond or stick together due to a lack of cohesion. The soil was found to be under the A-1-a subgroup considering the soil classification system of the American Association of State Highways and Transportation Officials (AASHTO), Further, the soil was classified as silty sands or sand silt mixture according to Unified Soil Classification System (USCS). In general, the material passed the DPWH requirements for Item 200 - Aggregate Subbase Course based on its physical and index property values.

Table 2. Summary of Physical and Index Properties of the Subbase Material

Property	Quantity
Gravel, %	0.00
Sand, %	91.00
Clay, %	9.00
Liquid Limit, %	26.00
Plastic Limit, %	Non-Plastic
Plasticity Index, %	Non-Plastic
AASHTO Classification	A-1-a
USCS Classification	SM

3.2. Compaction and California Bearing Ratio Tests

The soil sample was subjected to a compaction test based on the modified proctor compaction test method to obtain the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC). The MDD and OMC values were displayed in Table 3. The CBR value of 103.9% surpassed the requirement of 30% CBR soaked value of the DPWH for Item 200 – Aggregate Subbase Course.

Table 3. Summary of Compaction Test and CBR Test Results of the untreated subbase course

Mixture ID	Tests	Result
Subbase Materials	Maximum Dry Density (Kg/cu.m.)	2020
	Optimum Moisture Content (%)	8.6
	California Bearing Ratio (%)	103.9

3.3. Compaction behaviour of treated subbase course

The compaction results of the treated soil samples were shown in Table 4. The treated soil sample A obtained a highest MDD of 1910 kg/ m^3 with OMC of 12.2% while soil sample F had a lowest MDD of 1748 kg/ m^3 with OMC of 16.0%. Further, as the fly ash was added to the mixtures, the MDD values decreased. The incorporation of 1% cement into the mix resulted in greater density, resulting in the flocs repositioning, hence showing denser compacts.

Table 4. MDD and OMC of treated samples

Soil Samples	Aggregate Base/Subbase Course	(% OPC + %LSA+ %FA)	MDD (Kg/m^3)	OMC (%)
A	100% Soil	1%OPC +10%LS	1910	12.2
B	100% Soil	1%OPC +10%LS + 10% FA	1869	12.0
C	100% Soil	1%OPC +10%LS + 20% FA	1854	14.4
D	100% Soil	1%OPC +10%LS + 30% FA	1902	13.9
E	100% Soil	1%OPC +10%LS + 40% FA	1824	13.6
F	100% Soil	1%OPC +10%LS + 50% FA	1748	16.0

3.4. CBR Values of untreated and treated subbase course

Table 5 shows the CBR values of the mixture. Among the mixtures added with lime sludge, OPC, and FA, the addition of 50% FA gave the highest CBR value at 287%, while the lowest CBR value of 31% was observed from the mixture added with 10% fly ash. Coban (2017) observed similar results in his study on the use of lime sludge as soil stabilizer. He said that this is because the lower lime sludge content did not respond as effectively in flocculation, the CBR value barely changed, and higher lime sludge contents were required to achieve this.

Table 5. CBR values of the mixtures

Soil Samples	Aggregate Base/Subbase Course	(% OPC + %LS+ %OPC)	CBR Value (%)
A	100% Soil	1%OPC +10%LS	62
B	100% Soil	1%OPC +10%LS + 10% FA	31
C	100% Soil	1%OPC +10%LS + 20% FA	122
D	100% Soil	1%OPC +10%LS + 30% FA	170
E	100% Soil	1%OPC +10%LS + 40% FA	178
F	100% Soil	1%OPC +10%LS + 50% FA	287

It could also be observed that the CBR value of 31% obtained by the soil sample added with 1% have already passed the minimum requirement of 30% soaked CBR Value for Item 200 – Aggregate Subbase Course as stipulated in the DPWH Blue Book which means that this mixture could already be considered for adaptation depending the on the pavement design parameters.

Moreover, soaked CBR value amplified along with the increased amount of fly ash from 10% to 50% obtaining the highest CBR value at 50% fly ash addition equal to 287%. This increase in CBR was a result of the pozzolan reaction between alumina and silica of cement, lime sludge, and fly ash with water. According to Cherian and Arnepalli [30], pozzolan reactions started when the hydroxyl ion increased from the lime leading to a pH rise in the soil's water, with which the silicate and the aluminum sheets may start to dissolve. An increase on the CBR values of soils treated with lime sludge was also observed by Daleon and Lorenzo [8] in their study on the treatment of clay soil with sugar-mill lime sludge. They explained that, as silica and/or alumina are released, they can be combined with calcium to form hydrates of calcium silicate and/or calcium aluminium, which can be used to cement the soils together. After reaching its peak value, the CBR value decreased as the amount of lime sludge was further increased to 16%. This may be attributed to carbonation reactions which happen due to the presence of excess lime that reduces the bearing capacity of the soil.

4. CONCLUSION

Based on the laboratory results, the material has passed the specifications stipulated in the DPWH Blue Book for Item 200. For the treated mixture, the CBR values increase as the percentage addition of fly as also increases. It is then concluded that the OPC, LS, and FA can be used as stabilizing agent to improve the California Bearing Ratio of the subbase coarse material**.**

5. ACKNOWLEDGEMENT

The authors would like to thank the University of Science and Technology of Southern Philippines in Cagayan de Oro City, Philippines for funding this research study.

6. REFERENCES

[1] Coban, H. S. (2017). The use of lime sludge for soil stabilization. *Doctoral dissertation, Iowa State University*.

[2] Joe M. & Rajesh, A. (2015). Soil stabilization using industrial waste and lime. *International Journal of Scientific Research Engineering & Technology*, 4(7), 799-805.

[3] Alhassan, M., & Mustapha, A. M. (2007). Effect of Rice Husk Ash on Cement Stabilized Laterite. *Leonardo Electronic Journal of Practices and Technologies*, 11, 47-58.

[4] Zorluer, I., & Gucek, S. (2020). The usability of industrial wastes on soil stabilization. *Revista de la construcción*, *19*(1), 80-89.

[5] James, J., & Pandian, P. K. (2016). Industrial wastes as auxiliary additives to cement/lime stabilization of soils. *Advances in Civil Engineering*, *2016*.

[6] Chandak, N. R., & Babu, A. (2015). Effect of lime sludge on strength and compaction of soil. *J Civ Eng Res*, *5*(1), 18-20.

[7] Nagaraju, V. & Kumar, S. (2017). An experimental study on paper mill lime sludge as stabilizing agent. *International Journal of Innovative Research in Science, Engineering and Technology*, 6(1), 1005-1010.

[8] Daleon, C. F., Lorenzo, G. A. (2017). Effects of Sugar Mill Lime Sludge Treatment on the CBR and UCS of Expansive Soil in Bukidnon. *CMU Journal of Science*, *21*, 16-26.

[9] Suthar, M., & Aggarwal, P. (2018). Bearing ratio and leachate analysis of pond ash stabilized with lime and lime sludge. *Journal of Rock Mechanics and Geotechnical Engineering*, *10*(4), 769-777.

[10] Usha, M. (2016). Soil stabilization for pavement using lime and hyposludge. *International Journal of Advanced Research Trends in Engineering and Technology*, 3(2), 333-337.

[11] Roy, A. (2014). Soil stabilization using rice husk ash and cement. *International journal of civil engineering research*, *5*(1), 49-54.

[12] Simatupang, M., Mangalla, L. K., Edwin, R. S., Putra, A. A., Azikin, M. T., Aswad, N. H., & Mustika, W. (2020). The mechanical properties of fly-ash-stabilized sands. *geosciences*, *10*(4), 132.

[13] Turan, C., Javadi, A., Vinai, R., Shariatmadari, N., & Farmani, R. (2020). Use of class C fly ash for stabilization of fine-grained soils. In *E3S Web of Conferences* (Vol. 195, p. 06001). EDP Sciences.

[14] Unsever, Y.S., & Diallo, M.L. (2019). Stabilization of clay soils using fly ash. *Black Sea Journal of Engineering and Science*, *2*(3), 81-87.

[15] Sharma, R. K., & Hymavathi, J. (2016). Effect of fly ash, construction demolition waste and lime on geotechnical characteristics of a clayey soil: a comparative study. *Environmental Earth Sciences*, *75*(5), 1-1.

[16] Dahale, P., Nagarnaik, P., & Gajbhiye, A. (2016). Effect OF flyash and lime on stabilization of expansive soil. *Journal on Civil Engineering*, *6*(2), 8.

[17] Balangao, J. K. B., Tuyor, M. P., Salcedo, A., Namoco, C. S., & Jabile, L. M. (2022). DESIGN AND DEVELOPMENT OF A MANUALLY-OPERATED HYDRAULIC HOT-PRESSING MACHINE FOR AGRICULTURAL WASTES-BASED PARTICLEBOARD APPLICATION. *Science International (Lahore)*, *34*(6), 545-548.

[18] Jabile, L. M., Tuyor, M. P., Salcedo, A., Balangao, J. K. B., & Namoco, C. S. (2022). UTILIZATION OF SAWDUST AND RICE HUSK FOR PARTICLE BOARD APPLICATION. *ARPN Journal of Engineering and Applied Sciences*, *17*(2), 257-261.

[19] Jabile, L. M., Balangao, J. K. B., Namoco, C. S., Dumanat, D. R. A., & Relacion, J. P. M. (2022). Assessing the suitability of fly ash and rice husk ash from Misamis Oriental, Philippines in producing bricks for pedestrian and light traffic applications. *Journal of Biodiversity and Environmental Sciences| JBES*, *20*(1), 10-23.

[20] Baguhin, I. A., & Cabahug, R. R. (2019). Investigation on Load-Bearing Concrete Hollow Block Reinforced with Coconut Coir Fiber. *Mindanao Journal of Science and Technology*, *17*.

[21] Balangao, J. K. B., & Ramos, M. S. K. (2019). Production of Autoclaved Aerated Concretes with Fly Ash from a Coal Power Plant in Misamis Oriental, Philippines. *Indian Journal of Science and Technology*, 12*(*14), 1-16.

[22] Khairul Nizar, I., Al Bakri, A. M., Abd Razak, R., Kamarudin, H., Abdullah, A., & Zarina, Y. (2014). Study on physical and chemical properties of fly ash from different area in Malaysia. *Key Engineering Materials*, 594-595, 985-989.

[23] Bada, S. O., & Potgieter-Vermaak, S. (2008). Evaluation and treatment of coal fly ash for adsorption application. *Leonardo Electronic Journal of Practices and Technologies*, *12*, 37-48.

[24] Xu, M., Yan, R., Zheng, C., Qiao, Y., Han, J., & Sheng, C. (2004). Status of trace element emission in a coal combustion process: a review. *Fuel Processing Technology*, *85*(2-3), 215-237.

[25] Levandowski, J., & Kalkreuth, W. (2009). Chemical and petrographical characterization of feed coal, fly ash and bottom ash from the Figueira Power Plant, Paraná, Brazil. *International Journal of Coal Geology*, *77*(3-4), 269-281.

[26] Balangao, J. K. B., Podiotan, F. J. C., Ambolode, A. E. C., & Anacleto, N. M. (2022). ISOTHERMAL REDUCTION SMELTING OF MIXED CHROMITE-LATERITE SAMPLES WITH COCONUT CHARCOAL AS REDUCTANT UNDER ARGON ATMOSPHERE IN A VERTICAL ELECTRIC ARC FURNACE. *International Journal of Mechanical Engineering and Technology*, *13*(5), 46-53.

[27] Balangao, J. K. B., Podiotan, F. J., Ambolode, A. E. C., Anacleto, N. M., & Namoco, C. S. (2018). Production of Iron-Chromium-Nickel Metal Alloys Via Reduction of Mixed Chromite Ore from Zambales and Laterite Ore from Taganito, Surigao del Norte under Argon Atmosphere. *Indian J. Sci. Technol*, *11*, 1-11.

[28] Getes, E. L. A., & Caingles, V. K. S. (2022). Evaluation of the compressive strength of paver blocks with the inclusion of Mangima stone and Eggshell powder. *International Journal of Health Sciences*, *6*(S3), 12044–12053.

[29] Xue, Y., Hou, H., Zhu, S., & Zha, J. (2009). Utilization of municipal solid waste incineration ash in stone mastic asphalt mixture: Pavement performance and environmental impact. *Construction and Building Materials*, *23*(2), 989-996.

[30] Cherian, C., & Arnepalli, D. N. (2015). A critical appraisal of the role of clay mineralogy in lime stabilization. *International Journal of Geosynthetics and Ground Engineering*, *1*, 1-20.