Stabilization of Soil with Fly Ash and GGBS for Subgrade and Backfill Material

M. H. Sajid[1], Dr. Md. W. Rahman[2], E. Roy[3], A. Debnath[4], T. Ridoy[5]

[1] *Graduate Student, Department of Civil Engineering, AUST, Bangladesh, mhossen.sajid@gmail.com*
[2] *Visiting Professor, Department of Civil Engineering, AUST, Bangladesh, romudhaka@yahoo.com*
[3] *Graduate Student, Department of Civil Engineering, Texas State University, USA emonroy.cuet@gmail.com*
[4] *Graduate Student, Department of Civil Engineering, AUST, Bangladesh, adnath44@gmail.com*
[5] *Graduate Student, Department of Civil Engineering, AUST, Bangladesh, tanjunashravi41@gmail.com*

Abstract

Subgrade improvement to a greater extent is required to build a non-fragile and comparatively robust highway. Because of depression of roads in Bangladesh, the quality of subgrade and backfill materials are very crucial. Utilization of industrial wastes is a cost-effective and environmentally friendly method. Materials like FA (Fly Ash) and GGBS (Ground Granular Blast Furnace Slag), are used to improve soil strength because of their availability. In this research, 30% Fly Ash, 20% GGBS, 30% GGBS, 15% GGBS+15% FA are compared, and 30% of Fly Ash helped most to get premium quality of backfill and subgrade materials. The highest strength obtained is 0.83MPa, which is very close to the standard strength of subgrade and backfill. Strength of materials is likely to increase further because of the pozzolanic reaction of Fly Ash and GGBS with soil particles. We performed Atterberg limit, Optimum Moisture Content, and Unconfined Compressive Strength Tests. Unconfined compressive strength was determined by compacting the specimens to their respective optimum moisture content and curing for 7, 14, 21 days.

Keywords: *Subgrade; Fly Ash; GGBS; Atterberg Limit; Pozzolanic Reaction.*

1. Introduction

Road pavement performance is supported and enhanced by subgrade and unbound granular layers that control a safe distribution of vehicles by inducing stress. So, roadway formation layers must have high strength and bearing capacity (Sabrin, Siddiqua, & Muhammad, 2019). Before the construction of a road, pavement, or railway track, subgrades are compacted and stabilized by the addition of GGBS, Fly Ash, or other modifiers. Concrete made with GGBFS continues to gain strength over time and has been shown to double its 28-day-strength over periods of 10 to 12 years (Subash, 2014). GGBS has the superiority of social, economic, and environmental benefits in soft soil treatment (Shao, Liu, Tao, & Lou, 2013).

The Atterberg limits, index properties including liquidity index, and other soil properties obtained by laboratory or field tests control soil engineering properties (Zha, Liu, Du, & Cui, 2008). A significant decline in soil quality occurred worldwide through adverse changes in physical, chemical, and biological attributes and contamination by inorganic and organic chemicals (Arshad & Coen, 1992). The process of improving the load-bearing capacity and engineering properties of subgrade soil to support pavements and structures termed as soil stabilization (Ogundare, Familusi, Osunkunle, & Olusami, 2018). Slope, bridge, and structural failures can be eliminated by the soil stabilization process. Fly ash for stabilization of soft subgrade is one of the solutions being evaluated (Acosta, Edil, Benson, & Program, 2003). The effective fly ash content for improving the engineering properties of the soil varies between 15 to 30%, depending upon the soil type (Ghais & Ahmed, 2014).

Fly ash is a waste product from the combustion of pulverized coal in electric power plants that faces increasing production and requires a large area for disposal (Ghazali, Muthusamy, & Wan Ahmad, 2019). It contains hollow spheres of silicon, aluminum, and iron oxides, and un-oxidized carbon. In general, the main elements include Si, Al, Fe, and Ca with small amounts of Mg, Ti, S, K, and Na (Han & Wu, 2019). The formation of cemented compounds characterized by their high shear strength and low volume change is caused by the time-dependent cementation process (pozzolanic reaction) (Zha et al., 2008). The soil-cement clusters are dispersed by fly ash into smaller clusters, thereby increasing the reactive surface for hydration and pozzolanic reactions (Horpibulsuk, Rachan, & Raksachon, 2009). The pozzolanic characteristics increase the organic soil's shear strength and bearing capacity after being stabilized by fly ash (Nath, Molla, & Sarkar, 2017). The properties of soil are improved by fly ash inclusion which is attributed to the pozzolanic reaction and pore refinement effect of fly ash (Sezer, Inan, Yilmaz, & Ramyar, 2006)**.** The plasticity index and shrinkage limit are reduced by fly ash and it also has a potential impact on the engineering properties of fine-grained soil (Erdal Cokca, 2001). Higher stiffness and modulus values were measured on projects using self-cementing fly ash, reclaimed hydrated fly ash subbase, or granular subbase (White, Harrington, & Thomas, 2005). As the base materials for the roads, backfilling, and improvement of soil bearing capacity of any structure fly ash can be added to the soil (Prabakar, Dendorkar, & Morchhale, 2004). To manufacture high-quality self-compacting concrete biomass fly ash concrete can be used (Cuenca, Rodríguez, Martín-Morales, Sánchez-Roldán, & Zamorano, 2013).

For many years, as a cementitious component of concrete, ground granulated blast furnace slag (GGBS) has been used in composite cement (DESTA & JUN, 2018). Samples were found to be durable in Wetting Drying, and Freezing-Thawing tests when treated with 25, 30% of GGBS and alkali solution having 1.0 Ms after curing for 28 days (Amulya & Ravi Shankar, 2020). The activating reaction rate for GGBS is slowed down by the activator-soil reactions in the stabilized soil; this effect is less significant in MgO-GGBS-stabilized soil than in $Ca(OH)_2$-GGBS-stabilised soil. Hence, the GGBS hydration rate in the former is less reduced by the soil than in the latter (Yi, Liska, Jin, & Al-tabbaa, 2016). The CBR value improved by 78.8% of that obtained for the sole GGBS mixture after the activation of 75% GGBS with 25% Cement Kiln Dust (CKD) indicating that the activation is very viable (Jwaida, Dulaimi, Jafer, & Atherton, 2017).

2. Methodology

The procedures used to sum up the methodology are very crucial. These methods have major importance to measure the strength of the soil. Industrial wastes (GGBS and Fly Ash) were in both granular form and fine form. The soil was dried up in the oven bringing up the grinding form to make a stronger bond of the mixture. The percentages of mixing elements have been measured through this methodology.

2.1 Source and Properties of Samples:

GGBS and Fly Ash were collected from Crown Cement Company, Dhaka Bangladesh for this research work, and fine aggregate was collected from an ongoing project of Roads and Highway Department, Bangladesh. All the samples were collected by maintaining proper care and consideration. GGBS was collected in granular form from the factory and later it was ground and prepared in an almost powdered form to increase its reactivity. The relative density of the GGBS was found 2.90 after the laboratory test. Specific gravity and moisture (%) of fly ash were found 2.53 and 3.20 respectively from laboratory tests. Fine aggregate was collected by maintaining proper packaging to maintain its original moisture content and other properties. Later grain size distribution was performed. Particles passing no. 4 sieve (4.75 mm) was used in this study.

2.2 Sample Preparation:

First, the overall experimental setup is explained in Table 1 and then the tests will be discussed.

Table 1: Name of Experiments with Mixing Ratio

Name of Experiment	Soil	GGBS	Fly Ash
Atterberg Limit Test	100%	0	0
Optimum Moisture Content Test	100%	0	0
	80%	20%	0
	70%	30%	0
	70%	0	30%
	70%	15%	15%
Sample Making	100%	0	0
	80%	20%	0
	70%	30%	0
	70%	0	30%
	70%	15%	15%
Unconfined Compressive Strength Test	100%	0	0
	80%	20%	0
	70%	30%	0
	70%	0	30%
	70%	15%	15%

2.3 Atterberg limit test:

Water contents at which marked changes occur in the engineering behavior of fine-grained soils are Atterberg limits. Fine-grained soils consist of particles smaller than 0.074 mm (#200sieve) and include silts and clays. The ratio of the weight of water to the weight of solids in a soil mass is termed as water content and expressed as a percentage (Godwin & Escandon, 2017).

2.4 Liquid Limit Test:

The water content at which a groove is cut in a soil pat by a standard grooving tool and requires 25 blows to close for 13 mm when the LL-apparatus cup drops 10 mm on a hard rubber base is called the liquid limit. The liquid limit value ranges from zero to 1000, where most soils have LL values less than 100 (Godwin & Escandon, 2017).

2.5 Plastic Limit Test:

The water content at which a thread of soil rolled gently on a frosted glass plate to 3 mm diameter, crumbles into segments 3 mm–10 mm long is termed as the plastic limit test. The PL test is somewhat random and at least three trials are required to be performed and the average value is noted. The PL ranges from zero to 100, with most soils having values less than 40 (Godwin & Escandon, 2017).

2.6 Optimum Moisture Content Test:

To determine the relationship between the moisture content and dry density of a soil this test is performed and the optimum water content at which maximum dry density of soil can be attained through compaction, is determined through this test. The ability to attain acceptable levels of compaction is related to the moisture content of the soil. This test is conducted to determine the amount of compaction required by soil and the optimum moisture content for compaction. The soil compacted higher than optimum moisture content results in a relatively dispersed structure that is weaker, more ductile, susceptible to shrinking, less pervious, softer, and susceptible to swelling than compacted of optimum to the same density. The soil compacted lower than the optimum moisture content has the opposite characteristics of the soil compacted higher than the optimum moisture content in soil structure.

2.7 Unconfined Compressive Strength Test:

To determine the compressive strength of the sandy soil sample with the addition of fly ash in percentages as a stabilizing agent unconfined compressive strength test is performed (Ige & Ajamu, 2015). After determining the unconfined compressive strength, it's used to calculate the unconsolidated undrained shear strength of the clay under unconfined conditions. For maintaining the proper moisture content of the mixture, an optimum moisture content test was conducted. This method was used for 3, 7, 21 days to determine the increase in strength eventually. It indicates how the soil possesses cohesive strength. The values of unconfined compressive strength of different specimens are required to get the large strength value with proper percentages of mixing elements.

3. Results and Discussions

In this research work, the soil was mixed with Fly Ash and GGBS in many proportions to increase the soil strength that soil can be used for different purposes.

3.1 Discussion on Plastic Limit of Samples:

From the experimental procedures explained above the plastic limit of the samples was found between 22 and 26 percent. Researchers have explained that plastic limit generally varies from 20 to 25 percent for loamy soil having clay ratio 0.30 to 0.40 and 25 to 30 percent for clay ratio 0.75 to 0.80. Here, our result explains that our tested soil sample has a maximum clay ratio of 0.40.

3.2 Discussion on Liquid Limit of Samples:

The limiting moisture content at which the cohesive soil passes from the liquid state to the plastic state is the liquid limit. From experimental data, the liquid limit of our samples was found between 35 and 40 indicating that our soil samples are of clay of intermediate plasticity (CI). As we know that the plasticity index (PI) is the difference between liquid limit and plastic limit; PI for our tested sample is approximately 12-14 indicating medium plasticity of the samples.

3.3 Discussion on Optimum Moisture Content of Samples:

Compaction tests for soils were performed on mixers with 30% GGBS, 30% Fly Ash, 15% GGBS + 15% Fly Ash and simple soil. The optimum moisture content of the mixture varies with the percentage of material used and with the types of material. The highest value of compaction was for simple soil (21%). The lowest OMC value was for 30% Fly Ash. But when mixed with 30% GGBS, the OMC value became greater than that of 30% Fly Ash. So, it is also to be noted that after mixing GGBS or Fly Ash, the optimum moisture content of the soil decreases. Results of optimum moisture content for different mixture is shown below in Figure 1.

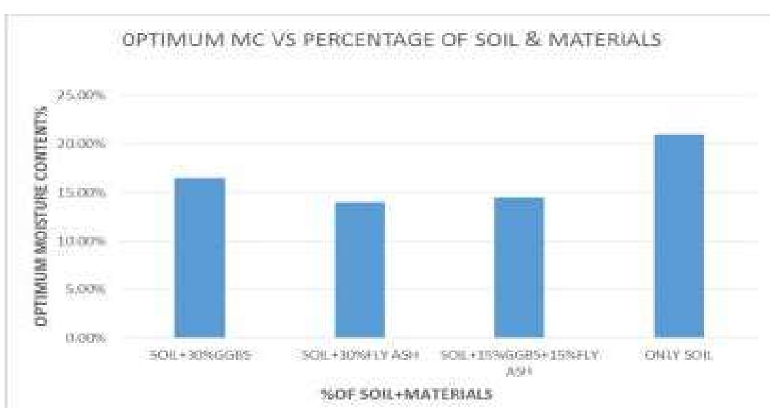

Figure 1: Optimum Moisture Content regarding different mixtures

3.4 Discussion on UCS Test of Samples:

The initial dry unit weight of soil predominantly affects the UCS of clay and as the initial density of clay increases, UCS also increases (Parihar & Shukla, 2015). A comparison of three different ratios of mixtures is going to be presented below.

3.4.1 First Ratio:

Comparison of ultimate strength of simple soil, soil+ 15% GGBS+15% Fly Ash, Soil+30% GGBS, Soil+20% GGBS, Soil + 30% Fly Ash is explained in Figure 2.

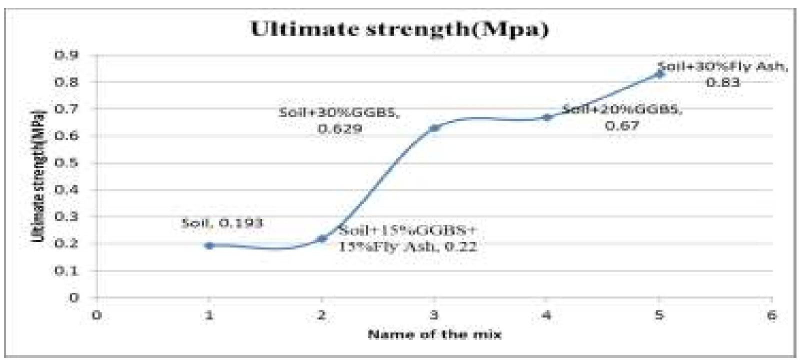

Figure 2: Comparison among Ultimate Strength According to First Ratio

This figure shows the comparison among soil mixed with 15% GGBS+ 15% Fly ash, 30% GGBS, 20% GGBS, and 30% Fly ash. Normal soil gives the lowest ultimate strength on the 21st day where soil with 30% Fly Ash gives the highest value for the same period. After mixing with materials such as GGBS and Fly Ash, the sandy properties increase, and the proportion of clay material decreases. For this reason, the ultimate strength increased with the increment in proportion mixing with soil. Moreover, the 20% GGBS mix with the soil gave a better value than 30% GGBS with soil. 20% GGBS mix with soil has a liquid limit of 45.4 and a plastic limit of 22.02%, where 30% GGBS mix with that soil has a liquid limit of 39 and a plastic limit of 22.02%. So, it is clear that GGBS is suitable for more clayey soil, and 20% GGBS is the optimum amount. But 15% GGBS+15% Fly Ash gave the lowest value among all the mixtures. It may be happening because the GGBS is not a much finer particle. According to the Highway Authority and Utility Committee for backfill material, it is necessary to gain 1 MPa strength in 90 days. But in our experiment, the ultimate strength of our sample increased 0.83 MPa within just 21 days. We are hopeful that after 90 days, an increase in strength will be much higher than 1 MPa. So, this proportion is suggested to use as backfill material.

3.4.2 Second Ratio:

The ultimate strength of soil+ 15% GGBS+15% Fly Ash is lower than the Soil+30% Fly Ash mixture. It might have occurred due to many reasons.

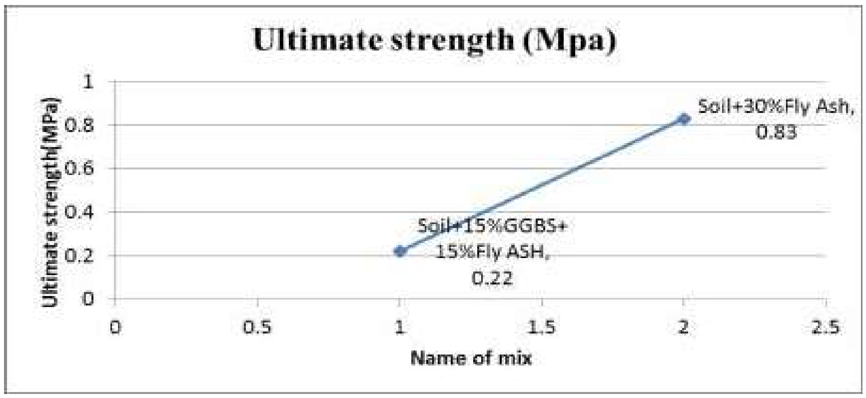

Figure 3: Comparison between Ultimate Strength According to Second Ratio

The Fly Ash is a common material in the two test components where GGBS is the new one. Moreover, the amount of Fly Ash also varied in the experiments. Here the GGBS is not a fine particle. So, it may delay taking chemical reaction at the granular size. On the other hand, it must be noted that the Fly Ash has more binding power than the granular GGBS material. The experimental values of ultimate strength are based on the second ratio shown in Figure 3.

3.4.3 Third Ratio:

Comparison of ultimate strength of soil with 30% GGBS and soil with 30% Fly ash will be discussed in this section. The variation in the experimental results occurred because of the different compositions of materials. Again, we must remember that GGBS is not a fine particle and it is a granular particle. So, the difference in results could happen as the chemical reaction of granular GGBS with soil is very slow than the finer particle. Moreover, when the sample was mixed with a large amount of GGBS; it could not pass through the sieve for its granular size. For this reason, it was considered an approximate percentage of GGBS. Lack of GGBS might be the reason of lower strength. The results of this ratio are provided in Figure 4.

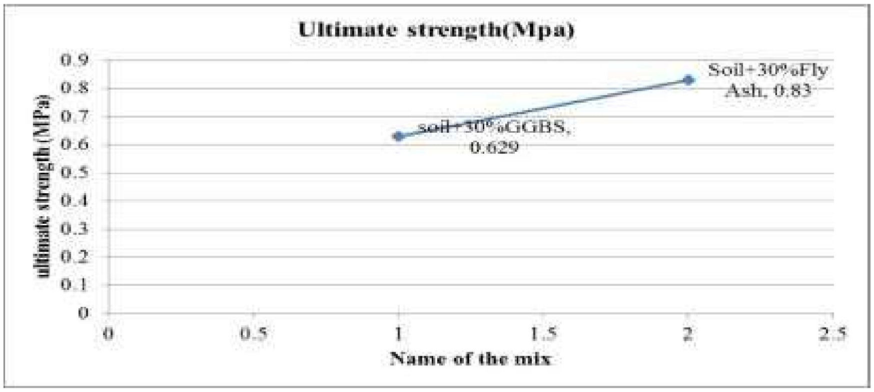

Figure 4: Comparison between Ultimate Strength according to the Third Ratio

4. Conclusion

The primary objective of this research work was to find the maximum strength by mixing various proportions of stabilized materials with soil. Here the soil was mixed with 20% GGBS, 30% GGBS, 30% Fly Ash and 15% GGBS + 15% Fly Ash. Researchers compared test results with the required strengths for road subgrade and backfill.

1. Adding GGBS and Fly Ash both reduced the optimum moisture content in the soil. But the use of only Fly Ash with soil helps to reduce optimum moisture content in the soil more than the use of GGBS.
2. For GGBS, 20% GGBS mix with the soil gave a better value than 30% GGBS with soil. Every binder has its optimum percentage for which it shows the best result. In this case, the optimum percentage of GGBS was observed between 20 to 30 percent. When it gets close to 30%, it gradually showed lesser reactivity hence lesser binding property.
3. According to the Highway Authority and Utility Committee for backfill material, it is necessary to gain the strength of 1 MPa in 90 days. But this study showed that the strength increment of soil mixed with 30% Fly Ash is 0.83 MPa within 21 days.
4. Mixing GGBS with Fly Ash increased the strength of the mixes. But it has to be kept in mind that the strength mainly depends on the percentage of materials mixed and it increases with time. Therefore, this shows that GGBS and Fly Ash have contributed to the bond of the mixes, and the binding property is similar to the binding characteristics of cement, and the strength also increased with curing time.
5. Using fly ash in a practical field may cause air pollution because of its very fine spherical particle. To minimize this type of pollution proper dust control management should be implemented in the field.

As a future recommendation, the researchers suggest using more finer particles of GGBS to get a better result as larger particles of GGBS induce slow chemical reactions with soil. The continuation of the proposed research work along with the sustainable impact of the usage of FA and GGBS are currently under considerations by the researchers of this project.

References

1. Acosta, H. A., Edil, T. B., Benson, C. H., & Program, G. E. (2003). Soil Stabilization

and Drying. *Program*, (03).

2. Amulya, S., & Ravi Shankar, A. U. (2020). Replacement of Conventional Base Course with Stabilized Lateritic Soil Using Ground Granulated Blast Furnace Slag and Alkali Solution in the Flexible Pavement Construction. *Indian Geotechnical Journal*. https://doi.org/10.1007/s40098-020-00426-2
3. Arshad, M. A., & Coen, G. M. (1992). Characterization of soil quality: Physical and chemical criteria. *American Journal of Alternative Agriculture*, *7*(1–2), 25–31. https://doi.org/10.1017/S0889189300004410
4. Cuenca, J., Rodríguez, J., Martín-Morales, M., Sánchez-Roldán, Z., & Zamorano, M. (2013). Effects of olive residue biomass fly ash as filler in self-compacting concrete. *Construction and Building Materials*, *40*, 702–709. https://doi.org/10.1016/j.conbuildmat.2012.09.101
5. DESTA, E., & JUN, Z. (2018). *A Review on Ground Granulated Blast Slag GGBS in Concrete*. 5–10. https://doi.org/10.15224/978-1-63248-145-0-14
6. Erdal Cokca. (2001). Use of Class Cfly Ashes for the Stabilization of an Expansive Soil. *Journal of Geotechnical and Geoenvironmental Engineering*, *127(7)*(July), 568–573. https://doi.org/10.1017/CBO9781107415324.004
7. Ghais, A., & Ahmed, A. (2014). Fly Ash Utilization in Soil Stabilization. *International Conference on Civil, Biological and Environmental EngineeringAt: Turkey, Istanbul*, (1), 1–6.
8. Ghazali, N., Muthusamy, K., & Wan Ahmad, S. (2019). Utilization of Fly Ash in Construction. *IOP Conference Series: Materials Science and Engineering*, *601*, 012023. https://doi.org/10.1088/1757-899x/601/1/012023
9. Godwin, W., & Escandon, R. (2017). Tunnels. *Encyclopedia of Engineering Geology*, (August 2019), 1–5. https://doi.org/10.1007/978-3-319-12127-7
10. Han, F., & Wu, L. (2019). Industrial Solid Waste Recycling in Western China. In *Industrial Solid Waste Recycling in Western China*. https://doi.org/10.1007/978-981-13-8086-0
11. Horpibulsuk, S., Rachan, R., & Raksachon, Y. (2009). Role of fly ash on strength and microstructure development in blended cement stabilized silty clay. *Soils and Foundations*, *49*(1), 85–98. https://doi.org/10.3208/sandf.49.85
12. Ige, J. A., & Ajamu, S. O. (2015). Unconfined Compressive Strength Test of a Fly Ash Stabilized Sandy Soil. *International Journal of Latest Research in Engineering and Technology*, *1*(3), 1–11.
13. Jwaida, Z., Dulaimi, A., Jafer, H. M., & Atherton, W. (2017). *Soft Subgrade Stabilisation Using Cement Kiln Dust and Ground Granulated Blast Slag*. (June).
14. Nath, B. D., Molla, M. K. A., & Sarkar, G. (2017). Study on Strength Behavior of Organic Soil Stabilized with Fly Ash. *International Scholarly Research Notices*, *2017*, 1–6. https://doi.org/10.1155/2017/5786541
15. Ogundare, D. A., Familusi, A. O., Osunkunle, A. B., & Olusami, A. O. (2018). Utilization Of Geotextile For Soil Stabilization. *American Journal of Engineering Research (AJER*, (7), 224–231. Retrieved from www.ajer.org
16. Parihar, N. S., & Shukla, R. P. (2015). Unconfined compressive strength of geotextile sheets reinforced soil. *International Journal of Earth Sciences and Engineering*, *8*(3), 1379–1385.
17. Prabakar, J., Dendorkar, N., & Morchhale, R. K. (2004). Influence of fly ash on strength behavior of typical soils. *Construction and Building Materials*, *18*(4), 263–267. https://doi.org/10.1016/j.conbuildmat.2003.11.003
18. Sabrin, S., Siddiqua, S., & Muhammad, N. (2019). Understanding the effect of heat treatment on subgrade soil stabilized with bentonite and magnesium alkalinization.

Transportation Geotechnics, *21*, 100287. https://doi.org/10.1016/j.trgeo.2019.100287
19. Sezer, A., Inan, G., Yilmaz, H. R., & Ramyar, K. (2006). Utilization of a very high lime fly ash for improvement of Izmir clay. *Building and Environment*, *41*(2), 150–155. https://doi.org/10.1016/j.buildenv.2004.12.009
20. Shao, L., Liu, L., Tao, Y. M., & Lou, L. M. (2013). The application of ground granulated blast slag in soft soil treatment. *Applied Mechanics and Materials*, *405–408*, 262–269. https://doi.org/10.4028/www.scientific.net/AMM.405-408.262
21. Subash, T. (2014). High Strength Concrete using Ground Granulated Blast Furnace Slag (GGBS). *International Journal of Scientific & Engineering Research*, *5*(7), 1050–1054. Retrieved from http://www.ijser.org
22. White, D. J., Harrington, D., & Thomas, Z. (2005). Fly Ash Soil Stabilization for Non-Uniform Subgrade Soils, Volume I: Engineering Properties and Construction Guidelines. *Final Report*, *IHRB Proje*.
23. Yi, Y., Liska, M., Jin, F., & Al-tabbaa, A. (2016). Mechanism of reactive magnesia-GGBS soil stabilisation. *Canadian Geotechnical Journal*, *55*(3), 773–782.
24. Zha, F., Liu, S., Du, Y., & Cui, K. (2008). Behavior of expansive soils stabilized with fly ash. *Natural Hazards*, *47*(3), 509–523. https://doi.org/10.1007/s11069-008-9236-4