Journal of Engineering Issues and Solutions

Evaluation of groundnut shell for enhancing geotechnical performance of weak soil

Jhalak Man Basnet[1], Purnima Baidya[2], Bhim Kumar Dahal[1*]

[1] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, TU*

[2] *Central Department of Microbiology, Kathmandu, TU*

* *Corresponding email: bhimd@pcampus.edu.np*

Received: January 6, 2024; Revised: May 17, 2024; Accepted: May 24, 2024

doi: https://doi.org/10.3126/joeis.v3i1.61575

Abstract

This research delves into the persistent challenge of strengthening weak soil for infrastructural development, offering a promising solution using groundnut shell ash (GSA) as a soil improvement admixture. Through a comprehensive study of various geotechnical properties of soil, different proportions of GSA, both solely and as alkaline-activated, were used. The investigation evaluated Atterberg's limits, compaction characteristics, and unconfined compressive strength. Comparative analyses revealed the efficacy of these admixtures. Results indicated that alkaline-activated GSA demonstrated superiority across all geotechnical properties, notably transforming high-plastic soil into low-plastic soil, unlike GSA only treatments, which altered specific properties but failed to induce the desired transformation. Alkaline-activated GSA and GSA only treatment reduced the maximum dry unit weight and increased the optimum moisture content. However, the alkaline-activated GSA demonstrated a lesser decrease in unit weight, and the trend was found to be even better for the higher alkaline activator ratio. Moreover, alkaline-activated GSA enhanced the compressive strength of soil by 12.86 times at 10% GSA content, compared to the 2.2-fold increase achieved by soil treated only with GSA content of 6%. Therefore, the results underscore the potential benefits of using GSA as a viable agro-waste for sustainable soil stabilization of soil deposits in Kathmandu Valley, instilling optimism for its future application.

Keywords: *Agro waste, Alkaline activation, Groundnut shell ash, Lacustrine soil, Soil modification*

1. Introduction

From the very early days, mankind has faced infrastructure development problems due to weak soil having low bearing capacity and other weak geotechnical properties. Finding firm soil as a base for infrastructure development is not always possible. Various failures of structures can be seen, like settlement, tilting, bearing capacity failure, shear failure, etc. (Dixit, 2016). To overcome such problems, various techniques have been adopted since the very beginning, such as mechanical compactions, including static and dynamic compaction; chemical stabilizations, including cement, lime, and other chemicals; and the fibers, including natural and synthetics (Afrin, 2017; Negi et al., 2013). Existing chemical stabilizers have been prominently used to enhance soil properties (Andavan & Kumar, 2020; Dahal et al., 2018; 2019; Paikiey & Rabbani, 2017). However, the problem lies in the fact that these binders must be produced considering different aspects, such as cost-effectiveness, eco-friendliness, local availability, etc. Various other pozzolanic additives are also used to stabilize the soil, like bagasse, eggshell powder, Groundnut shell ash (GSA), fly ash, rice husk ash, etc. (Acharya et al., 2023; Mohd Osman et al., 2022; Priya & Singh, 2021), which are relatively cheap, readily available, and eco-friendly.

In 2016, 44 million tons of shelled peanuts were produced worldwide. Almost 70% of the world's groundnuts, used for a high-protein meal and vegetable oil, are produced in Asia. Shell compartments comprise 21-29% of the nuts, generating 11 million metric tons of waste annually. While some shells are used as biomass for energy, more are being disposed as waste (Sathiparan et al., 2023). One of the sustainable uses of groundnut shells could be utilizing this waste for enhancing weak soils. The GSA contains some of the oxides found in pozzolanas and Portland cement. The GSA can replace a certain percentage of ordinary Portland cement for concrete and soil stabilization purposes (Reddy et al., 2017). It can be found that the pozzolanic reactions are due to the addition of calcium-rich binders. This produces cementitious materials comprising calcium silicate hydrate (CSH) and calcium aluminate hydrates (CAH) (Cristelo et al., 2013; Silmi Surjandari et al., 2018). It can be used as a pozzolanic binding material to stabilize weak soil. (Adetayo et al., 2021; Emmanuel et al., 2022; Ijimdiya, 1999; Ijimdiyaa et al., 2012; Khushbu & Parmar, 2017; Mohd Osman et al., 2022; Premkumar et al., 2021; Salman, 2021; Venkatraman et al., 2018) summarized that these by-products having pozzolanic properties can be used as a soil additive to enhance the properties of weak soil.

Recently, researchers have been focused on techniques that are economical, environment-friendly, and effective alternatives to traditional binders like cement. Alkali activation can act as an alternative binder in the soil stabilization realm. It possesses the property to enhance the strength, density, plasticity characteristics, and other various properties of weak soil (Acharya et al., 2023; Cristelo et al., 2013; Ganesan et al., 2019; Kumar et al., 2019; Shekhawat et al., 2019; Slaty et al., 2013; Teing et al., 2019). The alkaline activation of soil works on the principle of an increase in the pH of pore fluid. As pH increases, the properties of clay particles, like cation exchange property and clay particle arrangement, also change, which causes clay particles to have face-to-face orientation and affect the shear strength of soil (Behak, 2017; Dahal et al., 2023; Gajo & Maines, 2007; Priya & Singh, 2021). Therefore, this study investigates the effects of GSA alone and alkaline-activated GSA on the soil from Kathmandu to evaluate its applicability in soil stabilization.

2. Materials and Methods

2.1 Soil

2.1.1 Sample collection

The soil sample was obtained from a construction site in *Thapathali*, Kathmandu, at a depth of approximately 3 m (with coordinates Latitude-27.649509, Longitude-85.56). Once collected, the soil was left for air drying within a laboratory environment for about 15 days. Subsequently, it was pulverized into fine particles using a rubber mallet hammer on a plastic sheet placed over a concrete surface (refer to Figure 1(a) for illustration). The pulverized soil was then sieved through a 425 μm IS sieve and stored in an airtight plastic bucket.

2.1.2 Soil properties

The natural soil was black, having a specific gravity of 2.51. The natural moisture content was obtained as 69.36%. After hydrometer analysis, it was found that it contains about 64.84% of silt particles and 16.16 % of clay particles. Furthermore, the compaction tests inferred the optimum moisture content (OMC) and maximum dry unit weight (MDW) as 33% and 14.15 kPa, respectively. The liquid limit (LL) and plasticity index (PI) of natural soil were 62.84% and 23.11%, respectively. According to the unified soil classification system (USCS), it is classified into high plasticity silt (MH). As the strength of the soil, the UCS of the compacted soil sample was found to be 90.87 kPa.

Figure 1: Preparation of materials: a) Soil, and b) GSA

2.2 Preparation of groundnut shell ash

The groundnut shell was collected from a local peanut factory, cleaned and dried the shell for 48 hrs., and incinerated in a combustion chamber at the same facility until it turned into a grey ash, as shown in Figure 1 (b). Next, the ash was sieved through a 425 µm IS sieve to obtain GSA. The specific gravity of GSA was measured and found to be 1.92. The chemical composition of GSA, according to various research articles, is presented in Table 1.

Table 1: Chemical composition of GSA

Oxides	(Alaneme et al., 2014)	(Mohd Osman et al., 2022)
CaO	11.23	15.63
SiO_2	41.42	51.54
Al_2O_3	11.75	22.45
Fe_2O_3	12.60	2.40
K_2O	11.89	-

2.3 Preparation of alkaline activator solution

An alkaline activator solution was prepared using NaOH and Na_2SiO_3. A concentration of 10 M NaOH solution was prepared by mixing the pellets with potable water, which was transparent in color. Similarly, a concentration of 2 M of commercially available Na_2SiO_3 was also prepared. The color of the standard Na_2SiO_3 solution formed was translucent, murky white. The NaOH and Na_2SiO_3 solutions were mixed, maintaining the 1:2 ratios, and agitated for 5 min for the homogeneous mixture. The preparation of alkaline activator solution is presented in Figure 2.

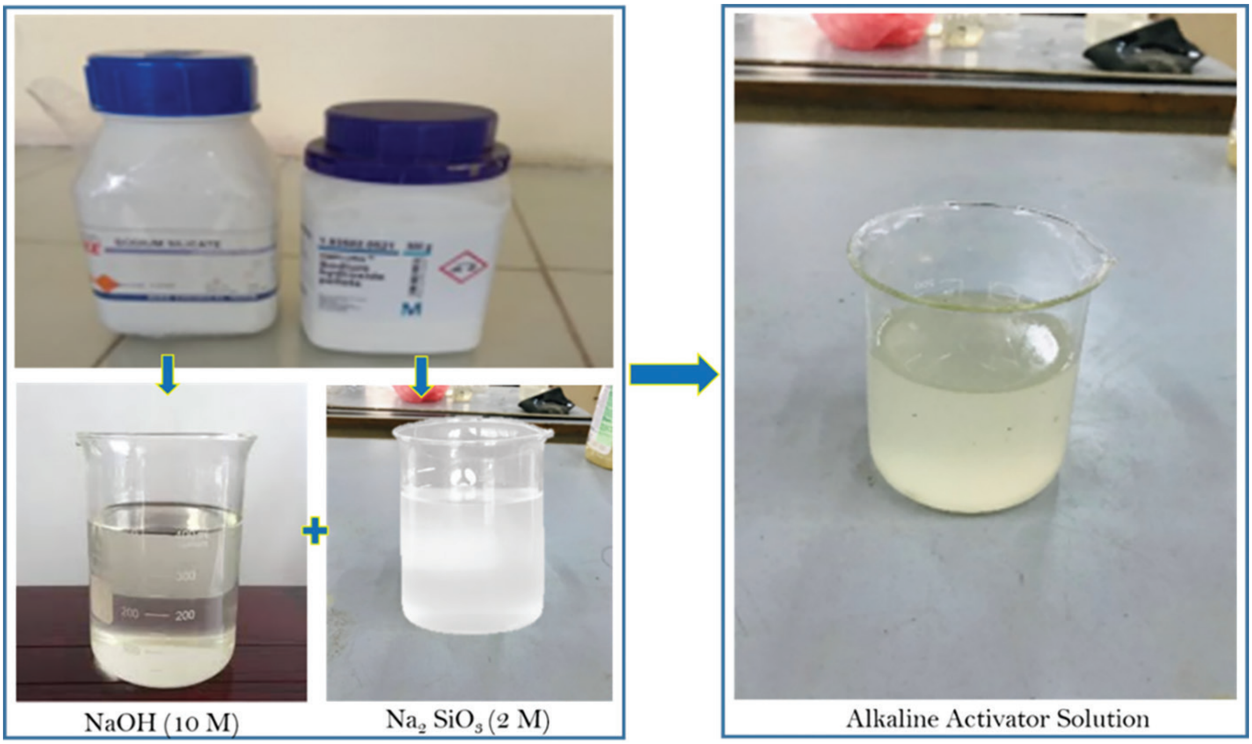

Figure 2: Preparation of alkaline activator solution

2.4 Experimental setup

Initially, various tests, including hydrometer analysis, specific gravity test, Atterberg's limit tests, compaction characteristics test, and unconfined compressive strength (UCS) test, were conducted on a natural soil sample according to Indian standards IS 2720. Both index and mechanical characteristics were evaluated to assess the effect of GSA on improving soil properties. Two sets of experiments were performed: in the first set, the natural soil was modified with varying amounts (2-10%) of GSA only. In the second set, the GSA was subjected to alkali activation to enhance the effect on soil characteristics, with alkaline activator ratios (AAR) of 0.25 and 0.65. After 28 days of curing, various tests were conducted on the modified soil. The compaction characteristics were determined using the Harvard miniature apparatus, which also prepared UCS samples at the corresponding optimum moisture content (OMC).

3. Results and Discussion

3.1 Effects of GSA on Atterberg's Limits

Atterberg's limit of soil treated with GSA is shown in Figure 3. For the soil modified with GSA only, the liquid limit (LL) initially decreased as GSA content increased up to 6%, after which it began to increase again (Figure 3(a)). Specifically, the LL decreased by approximately 9.78% at 6% GSA content compared to the natural soil sample, which had an LL of 62.84%. In contrast, when using alkaline-activated GSA, the LL gradually decreased with increasing GSA content. At a 0.25 AAR, the LL decreased by 20.86% with 10% GSA content compared to the natural soil. For the same GSA content but with a 0.65 AAR, the LL reduction was 22.82%, slightly higher than with the 0.25 AAR. Thus, while a higher AAR leads to a greater decrease in LL, the difference becomes less significant with increasing AAR.

Similarly, Figure 3(b) illustrates the variation in PL across different scenarios. For soil treated with GSA only, the PL increased with GSA content up to 6%, which decreased with further GSA addition. Compared to the natural soil sample, which has a PL of 39.73%, the PL increased by 3.45% at 6% GSA content and then declined to nearly the original value with 10% GSA. In the case of alkali-activated GSA, the PL gradually decreased as GSA content increased, showing a similar trend for both AARs of 0.25 and 0.65. The reduction in PL was more pronounced with higher AARs, with decreases of 15.23% and 17.57% for AARs of 0.25 and 0.65, respectively. Although a higher AAR resulted in a more significant decrease in PL, the difference in reduction became less significant with increasing AAR.

Additionally, Figure 3(c) depicts the variation in the PI of stabilized soils. Initially, the PI decreases with the addition of GSA up to 6%, after which it increases with further GSA additions for the samples treated with GSA only. At 6% GSA, the PI decreases significantly by approximately 32.54% compared to the natural soil sample (PI = 23.11%). Meanwhile, for alkali-activated GSA, the PI also decreases as GSA content increases, though the rate of decrease slows with higher GSA contents. The maximum reduction in PI is similar for both AARs, with reductions of 32.71% and 31.85% for AAR 0.25 and 0.65, respectively. Furthermore, with the increase in GSA content, it was found that the soil has shifted from high plastic silt (MH) to low plastic silt (ML). The decrease in LL and PL might be due to an increase in the size of the clay particles due to alkali-activated GSA. Similar results can be found in other similar research works (Acharya et al., 2023). Moreover, this decrease in PI is considered desirable for the construction of pavement and other infrastructure and signifies the use of GSA for soil modification.

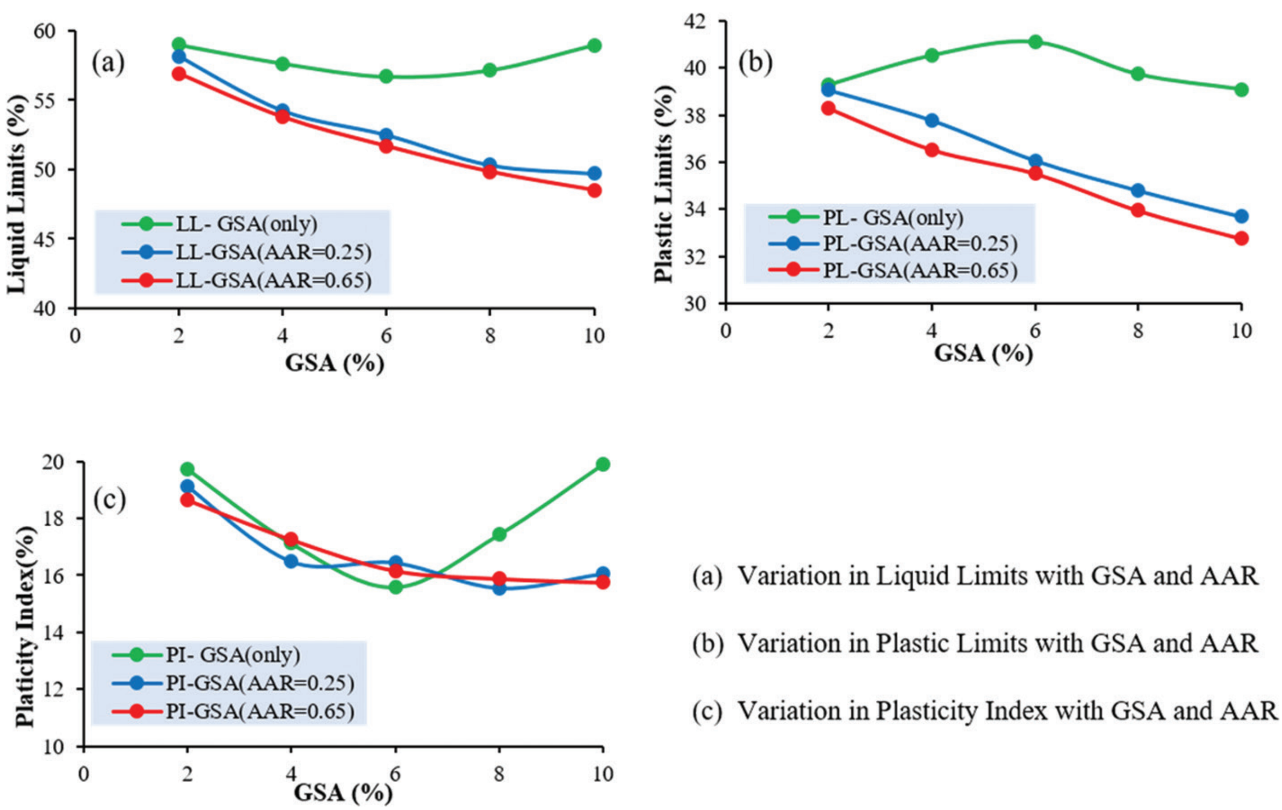

Figure 3: Variation in Atterberg's limits

3.2 Effects of GSA on compaction characteristics

Figure 4(a) shows that the MDW of modified soil decreases with the addition of GSA. For soil modified with GSA only, the MDW of the natural soil sample decreased from 14.15 kN/m³ to 12.35 kN/m³ when 10% GSA was added. This reduction in density is likely due to GSA particles, which have a lower specific gravity, displacing the soil particles. Similarly, soil samples treated with alkali-activated GSA exhibited a reduction in MDW with increasing GSA content for both alkali activator ratios (AAR). However, a higher AAR resulted in an increased MDW. For instance, with 10% GSA, the MDW for 0.25 AAR and 0.65 AAR were 13.05 kN/m³ and 13.25 kN/m³, respectively, which are 5.67% and 7.29% higher than the samples treated with GSA only. The increase in MDW with higher AAR is attributed to the increased alkali content, which enhances the concentration of cations attracted to negatively charged clay surfaces. This attraction draws water molecules towards the clay surface, separating clay particles and forming dispersed structures. These structures facilitate particle movement, reducing the void ratio and resulting in a denser matrix upon the same compaction (Acharya et al., 2023).

The OMC of the treated soil increased as the GSA content increased. Specifically, OMC increased from 33% in the natural soil to 37.5% in the treated soil when the 10% GSA content for specimens treated with GSA only (Figure 4(b)). This increase in the OMC can be attributed to the water required for pozzolanic reactions, which corroborates findings from prior studies (Mohd Osman et al., 2022). Furthermore, a similar trend was observed for alkali-activated GSA, where increased GSA content led to an increase in OMC. Except for a slight decrease at 2% GSA content. However, as the AAR increased, there was a reduction in OMC. Specifically, reductions of 5.33% and 6.67% were noted for AAR values of 0.25 and 0.65, respectively. This regain in OMC can be attributed to the alkali activation process, primarily driven by chemical reactions, pH elevation, and cation exchange processes associated with alkali activation (Dahal et al., 2023; Gajo & Maines, 2007).

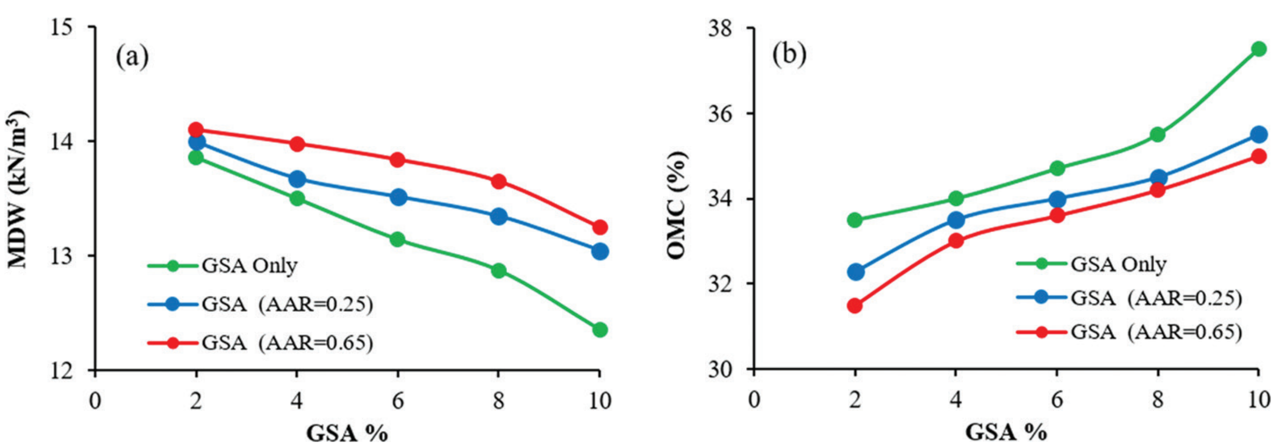

Figure 4: Variation in compaction characteristics with GSA content a) MDW, and b) OMC

3.3 Effects of GSA on compressive strength

It was found that the UCS of soil was increased with an increase in GSA content, as shown in Figure 5. The maximum UCS value of soil modified with GSA was only 2.2 times the UCS value of the natural soil sample. The maximum increment was observed at 6% GSA content, and a further increase in GSA content slightly affects the soil strength. An increase in the compressive strength of soil is due to a pozzolanic reaction between the soil and the GSA, it gives rise to the agglomeration and flocculation of the clay particles (Reddy et al., 2017).

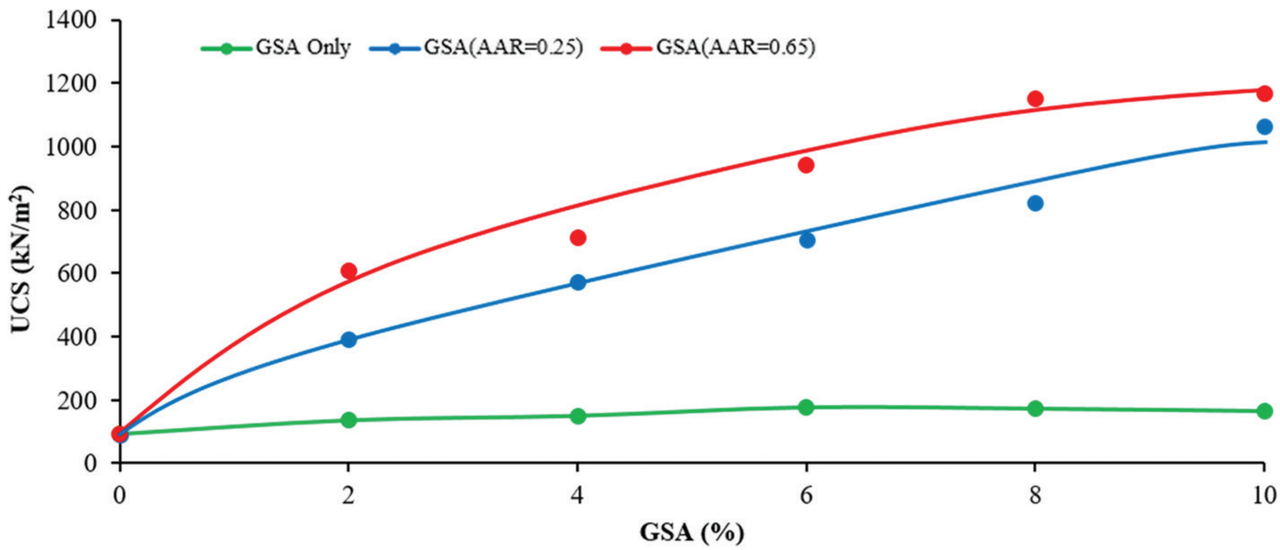

Figure 5: Variation of UCS with GSA content

Figure 5 also illustrates the UCS of soil modified using alkaline-activated GSA. In comparison to the strength of a compacted natural soil sample (90.87 kPa) and one modified with GSA only (202.35 kPa at 6% GSA content), the UCS for the specimen with 0.25 AAR showed a significant increase with alkali activation, reaching 1063.65 kPa at 10% GSA content. Notably, unlike the scenario with GSA only, where the maximum strength was achieved at 6% GSA content, the soil's strength continued to increase with GSA contents, and the increment was observed even higher for the GSA content beyond 8%. Similarly, higher compressive strength was observed for samples treated with GSA activated by 0.65 AAR. For instance, at 10% GSA content and 0.65 AAR, the strength after 28 days of curing reached 1168.23 kPa, nearly 13 times the strength of untreated compacted soil samples. Nevertheless, this study focuses on strength improvement up to 10% GSA content, which appears to be sufficiently enhanced for practical geotechnical loading conditions. This increased strength is attributed to various factors such as pozzolanic reactions, chemical processes like increase in pH, and cation exchange, all contributing to the cementation and agglomeration of soil particles (Dahal et al., 2023; Gajo & Maines, 2007; Reddy et al., 2017).

4. Conclusions

The laboratory investigation of soil modified with GSA revealed that alkali activation of GSA enhances its effectiveness in improving the physical and index properties of the soil, such as LL, PL, PI, compaction characteristics, and UCS. The alkaline-activated GSA, activated with 0.25 and 0.65 AAR, reduced LL by 20.86% and 22.82% and PL by 15.23% and 17.57%, respectively, while the GSA only reduced LL by 9.79% and increased PL by 3.45%. The soil modified with alkaline activated GSA also showed less decrease in MDW and less increase in OMC than the soil modified with GSA only. This trend was observed to be even more pronounced for the higher AAR. The soil treated with GSA only increased UCS value by 2.2 times at 6% GSA content and decreased slightly with a further increase in GSA content. On the other hand, in the soil treated with alkaline-activated GSA, the UCS was increased by 11.71 and 12.86 times compared to the compacted natural soil sample after 28 days of curing period. These results indicate that the alkali-activated GSA improves the shear strength and reduces the PI of the soil, which are desirable characteristics for geotechnical applications. However, the soil used in this study was collected from a specific location and may not represent the soil variability within Kathmandu Valley. Therefore, the findings of this study may not apply to other sites without further verification.

Acknowledgements

The authors would like to thank the Department of Civil Engineering, Institute of Engineering, Pulchowk Campus, for providing laboratory facilities to conduct this research.

References

Acharya, S., Niraula, U., & Dahal, B. K. (2023). Improving soft clay behavior with alkali-activated waste eggshell for sustainable ground engineering. *International Journal of Geosynthetics and Ground Engineering*, 9(5), 1–13. doi: https://doi.org/10.1007/s40891-023-00480-9

Adetayo, O. A., Amu, O. O., Faluyi, F., & Akinyele, E. (2021). Effect of groundnut shell ash on laterite soils stabilized with lime for civil structures. *International Journal of Integrated Engineering*, 13(4), 242–253. doi: https://doi.org/10.30880/ijie.2021.13.04.023

Afrin, H. (2017). A review on different types soil stabilization techniques. *International Journal of Transportation Engineering and Technology*, 3(2), 19. doi: https://doi.org/10.11648/j.ijtet.20170302.12

Alaneme, K. K., Fatile, B. O., & Borode, J. O. (2014). Mechanical and corrosion behaviour of Zn-27Al based composites reinforced with groundnut shell ash and silicon carbide. *Tribology in Industry*, 36(2), 195–203.

Andavan, S., & Kumar, B. M. (2020). Case study on soil stabilization by using bitumen emulsions – A review. *Materials Today: Proceedings*, 22, 1200–1202. doi: https://doi.org/https://doi.org/10.1016/j.matpr.2019.12.121

Behak, L. (2017). Soil stabilization with rice husk ash. In *Rice - Technology and Production*. InTech. Retrieved from https://doi.org/10.5772/66311

Cristelo, N., Glendinning, S., Fernandes, L., & Pinto, A. T. (2013). Effects of alkaline-activated fly ash and Portland cement on soft soil stabilisation. *Acta Geotechnica*, 8(4), 395–405. doi: https://doi.org/10.1007/s11440-012-0200-9

Dahal, B. K., Pokhrel, S., Basnet, S., Dahal, U., Sah, S. K., Neopane, S., … Timalsina, S. (2023). Effects of pore fluid's pH on the physico-mechanical behavior of high plasticity silt. *Ecological Engineering & Environmental Technology*, 24(8), 202–215. doi: https://doi.org/10.12912/27197050/171568

Dahal, B. K., Zheng, J.-J. J., Zhang, R.-J. J., & Song, D.-B. B. (2019). Enhancing the mechanical properties of marine clay using cement solidification. *Marine Georesources and Geotechnology*, 37(6), 755–764. doi: https://doi.org/10.1080/1064119X.2018.1484532

Dahal, B. K., Zheng, J. J., & Zhang, R. J. (2018). Experimental investigation on physical and mechanical behavior of Kathmandu clay. *Advanced Materials Research*, 1145, 112–116. doi: https://doi.org/10.4028/www.scientific.net/AMR.1145.112

Dixit, M. S. (2016). Damage mechanism in problematic soils. *International Journal of Civil Engineering and Technology*, 7(5), 232–241.

Emmanuel, U. S., E., Nyak E. E., & Agbor, R. B. (2022). Enhancement of soil stability with groundnut shell ash. *Journal of Civil Engineering Research*, 12(1), 1-7. doi: https://doi.org/10.5923/j.jce.20221201.01

Gajo, A., & Maines, M. (2007). Mechanical effects of aqueous solutions of inorganic acids and bases on a natural active clay. *Geotechnique*, 57(8), 687–699. doi: https://doi.org/10.1680/geot.2007.57.8.687

Ganesan, N., Ramesh Babu, C., & Meyyappan, P. L. (2019). Influence of alkaline activator ratio on compressive strength of GGBS based geopolymer concrete. *IOP Conference Series: Materials Science and Engineering*, 561(1), 1-6. doi: https://doi.org/10.1088/1757-899X/561/1/012083

Ijimdiya, T. S. (1999). Effect of groundnut shell ash on the particle size and plasticity characteristics of black cotton soil. *Nigerian Journal of Materials Science and Engineering*, 5(1), 68–72.

Ijimdiyaa, T. S., Ashimiyu, A. L., & Abubakar, D. K. (2012). Stabilization of black cotton soil using groundnut shell ash. *Electronic Journal of Geotechnical Engineering*, 17 Y(3), 3645–3652.

Khushbu, B., & Parmar, N. B. (2017). Use of ground nut shell ash and coal ash to modify the properties of soil. *International Journal of Advance Engineering and Research Development*, 4(05), 991–994. doi: https://doi.org/10.21090/ijaerd.87726

Kumar, S., Gautam, P. D., & Sarath, B. C. K. (2019). Effect of alkali activator ratio on mechanical properties of GGBS based geopolymer concrete. *International Journal of Innovative Technology and Exploring Engineering*, 8(12), 947–952. doi: https://doi.org/10.35940/ijitee.J9539.1081219

Mohd Osman, N. F., Ahmad Tajudin, S. A., & Pakir, F. (2022). The effect of groundnut shell ash on soil stabilization. *Journal of Sustainable Underground Exploration*, 2(1), 34–40. doi: https://doi.org/10.30880/jsue.2022.02.01.005

Negi, A. S., Faizan, M., & Siddharth, D. P. (2013). Soil stabilization using lime, 2(2), 448–453.

Paikiey, A., & Rabbani, A. (2017). Soil stabilisation using cement. *International Journal of Civil Engineering and Technology*, 8(6), 316–322. doi: https://doi.org/10.1016/0148-9062(77)90919-6

Premkumar, R., Subha, B., Sandhiya, S. P., & Narayanan, K. S. (2021). Stabilization of black cotton soil with groundnut shell ash. *Materials Research Proceedings*, 19, 44–50. doi: https://doi.org/10.21741/9781644901618-6

Priya, P., & Singh, D. R. V. (2021). Stabilization of black cotton soil using fly ash. *International Journal of Recent Technology and Engineering (IJRTE)*, 9(5), 91–96. doi: https://doi.org/10.35940/ijrte.e5164.019521

Reddy, M. V. S., Sasi, K., Ashalatha, K., & Madhuri, M. (2017). Groundnut shell ash as partial replacement of cement in concrete. *Research Journal of Science and Technology*, 9(3), 313. doi: https://doi.org/10.5958/2349-2988.2017.00056.0

Salman, A. M. (2021). Potential use of groundnut shell ash as soils strength enhancer. *LAUTECH Journal of Civil and Environmental Studies*, 6(1), 127–134. doi: https://doi.org/10.36108/laujoces/1202.60.0190

Sathiparan, N., Anburuvel, A., & Selvam, V. V. (2023). Utilization of agro-waste groundnut shell and its derivatives in sustainable construction and building materials – A review. *Journal of Building Engineering*, 66, 105866-105886. doi: https://doi.org/10.1016/j.jobe.2023.105866

Shekhawat, P., Sharma, G., & Singh, R. M. (2019). Strength behavior of alkaline activated eggshell powder and flyash geopolymer cured at ambient temperature. *Construction and Building Materials*, 223, 1112–1122. doi: https://doi.org/10.1016/j.conbuildmat.2019.07.325

Silmi Surjandari, N., Harya Dananjaya, R., & Jauharotus, E. S. (2018). The effect of egg shell powder on the compression strength of fine-grained soil. *MATEC Web of Conferences*, 195, 1–6. doi: https://doi.org/10.1051/matecconf/201819503011

Slaty, F., Khoury, H., Wastiels, J., & Rahier, H. (2013). Characterization of alkali activated kaolinitic clay. *Applied Clay Science*, 75–76, 120–125. doi: https://doi.org/10.1016/j.clay.2013.02.005

Teing, T. T., Huat, B. B. K., Shukla, S. K., Anggraini, V., & Nahazanan, H. (2019). Effects of alkali-activated waste binder in soil stabilization. *International Journal of GEOMATE*, 17(59), 82–89. doi: https://doi.org/10.21660/2019.59.8161

Venkatraman, K., Dayakar, P., & Venkatakrishnaiah, R. (2018). Study on effect of groundnut shell ash in index properties of clay soil. Acadpubl.Eu, 119(12), 9265–9277.