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Innovative Use of Sawdust Waste for Soil Stabilization: A Sustainable Approach in Geotechnical Engineering

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ABSTRACT

The need for low-carbon alternatives to traditional soil-stabilizing methods, including cement and lime, has grown in response to rising urbanization and the desire for more environmentally friendly infrastructure. Many studies have focused on sawdust ash or blended systems, but the behaviour of raw sawdust in clay soils, particularly under tropical conditions, has not been thoroughly investigated. This is although lignocellulosic waste materials, and sawdust in particular, offer a potentially environmentally friendly solution. Therefore, this study aims to investigate the effect of raw sawdust on the consistency limits and compaction characteristics of clay soil and to evaluate its potential as a sustainable soil stabilizer. Laboratory experiments were conducted using Atterberg Limits and Standard Proctor Compaction Tests on untreated soil (control) and soil treated with 5% sawdust by dry weight. The result shows that the plasticity index increased from 38.52% to 54.41%, indicating higher moisture sensitivity, while increases in liquid and plastic limits suggest reduced structural stability. Compaction results reveal a decrease in maximum dry density from 1.36 g/cm³ at 15.56% moisture content to 1.15 g/cm³ at 23.08%, reflecting the lightweight and hygroscopic nature of sawdust. Overall, while sawdust contributes to waste reduction and supports circular economy practices, it reduces soil strength and compaction efficiency, making it more suitable for non-load-bearing or lightly loaded applications, or when used in combination with stabilizing agents. This study provides important insights into the potential and limitations of raw sawdust for sustainable ground improvement.

1. Introduction

Rapid urbanization continues to place increasing pressure on the construction industry to deliver infrastructure with reduced embodied carbon and minimal long-term environmental impact. Ground improvement plays a critical role in this context, as subgrade quality directly influences pavement thickness, serviceability, and foundation durability. Conventional stabilizers such as

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Portland cement and lime are widely used and effective; however, their production is energy-intensive and associated with significant carbon emissions. In parallel, timber processing and biomass energy industries generate large volumes of lignocellulosic waste, including sawdust and wood ash, which are often underutilized or disposed of in landfills. The reuse of these by-products as soil stabilizers presents an opportunity to support circular economy principles while potentially reducing construction costs and environmental burdens. Sawdust may be utilized either in its raw form as a lightweight organic filler or after thermal conversion into sawdust ash (SDA) or wood ash (WA). Agaiby *et al.,*[1] reported that raw sawdust increases the optimum moisture content (OMC) and reduces the maximum dry density (MDD) of soils due to its low specific gravity and hygroscopic nature. In addition, the fibrous structure of sawdust may contribute to slight improvements in ductility and shear resistance at low dosages, although excessive inclusion can weaken soil structure.

In contrast, Rashidi *et al.,* [2] demonstrated that sawdust ash reduces plasticity through pozzolanic reactions, while Elahi *et al.,* [3] showed that the presence of reactive oxides such as CaO enhances strength development in treated soils. Fawaz *et al.,* [4] further substantiated that sawdust ash typically enhances the engineering properties of clay and lateritic soils more effectively than raw sawdust; however, the optimal dosage is contingent upon soil type. Anuar *et al.,* [5] found that sawdust ash can effectively improve peat soil stability, particularly when curing is considered, whereas Blayi *et al.,* [6] reported that wood ash enhances unconfined compressive strength (UCS) and California bearing ratio (CBR), although excessive ash content may reduce performance due to increased void ratio. These findings indicate that ash-based stabilizers are generally more effective than raw sawdust, particularly in strength enhancement, but their performance remains highly dependent on dosage and curing conditions. Govindasamy *et al.,* [7] emphasized that Atterberg limits are highly sensitive to stabilizer type and proportion, which points to the importance of systematic mix design. Mohamed *et al.,* [8] raised concerns regarding variability in ash chemistry, including free lime content and leachability, which may affect long-term durability and environmental safety. In comparison, Cazier *et al.,* [9] demonstrated that raw sawdust can reduce water absorption in earth-based materials, although strength improvements remain limited without cementitious binders. Kossi *et al.,* [10] found that sawdust raises OMC and lowers MDD in clay soils, but its effects on plasticity vary depending on the mineral makeup. Anuar *et al.,* [5] also noted that fiberized sawdust can improve shear resistance through frictional interlock but highlighted the risk of strength reduction at higher dosages due to void formation.

Studies on SDA-treated soils further highlight the advantages of ash-based stabilization. Fadele *et al.,* [11] stated that SDA lowers plasticity and raises UCS and CBR after the right amount of curing. Ekinci *et al.,* [12] demonstrated that wood ash contributes to both short-term cation exchange and long-term pozzolanic reactions, resulting in increased stiffness and reduced plasticity. However, Ercan *et al.,* [13] pointed out potential environmental risks such as heavy-metal leaching, raising the importance of proper material characterization. Comparative reviews also offer substantial information about stabilization performance. Ikeagwuani and Nwonu [14] concluded that the effectiveness of waste-derived stabilizers is strongly influenced by soil mineralogy, additive composition, and curing conditions, and stressed the importance of evaluating long-term durability and environmental impact. Nath *et al.,* [15] showed that wood ash can act as a reactive filler to improve compressibility and strength in fine-grained soils, while Blayi *et al.,* [6] confirmed that optimum ash content is critical to avoid performance degradation. Emeh and Igwe [16] further demonstrated that combining wood ash with lime produces synergistic effects, improving strength and reducing swelling potential more effectively than using ash alone. Microstructural evidence reported by Ekinci *et al.,* [12] supports this observation, indicating improved cohesion and reduced brittleness in blended systems. Karim *et al.,* [17] highlighted that curing time plays a significant role in strength development for SDA-treated soils, whereas Abu Zeid [18] reported that raw sawdust primarily increases moisture demand and reduces density, limiting its suitability for structural applications. Collectively, these studies indicate that while ash-based stabilizers consistently improve strength and plasticity, raw sawdust tends to increase water sensitivity and reduce compaction efficiency, making it more suitable for lightweight or non-load-bearing applications.

Despite the growing body of research on sawdust, sawdust ash, and other biomass-derived stabilizers, several gaps remain in the current understanding of their application in geotechnical engineering. Existing studies predominantly emphasize ash-based systems or blended binders, while the behavior of raw sawdust, particularly in tropical clay soils, has not been comprehensively evaluated. In addition, limited research provides direct comparisons between raw sawdust and its ash derivatives in terms of their influence on consistency limits and compaction characteristics, especially under local Malaysian subgrade conditions. Therefore, this study aims to (i) investigate the effect of raw sawdust on the consistency and compaction characteristics of a local clay soil and (ii) contextualize the findings with existing SDA and WA studies to delineate realistic mix-design strategies for sustainable subgrade applications. The significance of this study lies in its contribution to sustainable ground improvement practices through the valorization of timber waste, reduction of dependence on conventional high-carbon stabilizers, and support for circular economy principles in construction, thereby aligning with the increasing demand for environmentally responsible infrastructure development.

2.0 Methodology

2.1 Materials

Clay soil used in this study was obtained from a local borrow pit to represent typical fine-grained material commonly encountered in subgrade and earthwork applications. The collected soil was air-dried in the laboratory to remove natural moisture while preserving its mineralogical characteristics, then gently disaggregated and sieved through a 0.425 mm sieve to ensure material homogeneity and repeatability in laboratory testing, as recommended for consistency and compaction analyses of clayey soils as stated by Fawaz *et al.,*[4] and Chinkhuntha *et al.,* [19].Sawdust was obtained from a nearby timber processing company and chosen as a representative lignocellulosic waste material because of its growing use in sustainable soil improvement research. The sawdust was first air-dried to a constant mass before being oven-dried at 60 °C for 12 hours to remove residual moisture without thermally degrading the organic fibers, as reported in recent studies on sawdust-modified clay soils by Iliyas *et al.,*[20]. The dried sawdust was sieved to a particle size of less than 1.0 mm to improve dispersion within the clay matrix and promote effective soil-additive interaction, which has been proven to improve uniformity and consistency in treated soils. In this study, a sawdust content of 5% by dry mass of soil was used, as recent studies by Fawaz *et al.,*[4], have shown that low-percentage sawdust additions (typically 2-10%) are effective in modifying the plasticity and compaction characteristics of clay soils without introducing excessive organic matter, which could harm engineering performance. Distilled water was used during sample preparation and testing to remove the influence of dissolved salts and contaminants on soil consistency and compaction behavior, as advised by recent geotechnical research, Iliyas *et al.,* [20].

2.2 Experimental Design and Mixing

Two soil mixtures were evaluated in this study: untreated clay serving as the control mix and clay treated with 5% sawdust by dry mass of soil. This comparison was designed to isolate the effect of the lignocellulosic amendment on the consistency and compaction behavior of the clay. For each laboratory test, three replicate specimens (n = 3) were prepared for both the control and treated mixes to ensure statistical reliability and to minimize experimental variability. For sample preparation, the required quantities of dry clay and sawdust were first weighed accurately and dry-mixed for approximately 2–3 min to achieve a uniform distribution of the additive within the soil matrix. This initial dry blending step was essential to prevent particle segregation and to ensure consistent interaction between clay particles and sawdust fibers. Distilled water was then added gradually while mixing continued for an additional 5–7 min until the target workability appropriate for each test was achieved. The incremental addition of water was adopted to avoid localized oversaturation and to promote homogeneous moisture distribution throughout the mixture. For the treated specimens, the freshly mixed soil–sawdust batches were sealed in airtight containers and allowed to mellow for a period of 12–24 h prior to testing. This mellowing period was incorporated to accommodate delayed water absorption by the sawdust particles and to allow moisture equilibration within the composite soil matrix. Such conditioning is particularly important for organic amendments with high water absorption capacity, as it helps stabilize the effective moisture content and improves repeatability of subsequent consistency and compaction measurements. In contrast, control specimens were tested shortly after mixing to reflect the immediate response of untreated clay under comparable laboratory conditions. Overall, the adopted mixing, conditioning, and replication procedures were intended to ensure consistency between test specimens and to provide a reliable basis for comparing the behavior of untreated and sawdust-treated clay soils.

2.3 Atterberg Limits

Atterberg's limits testing was conducted to assess the effect of sawdust addition on the consistency and plasticity of the clay soil. Specimen preparation followed ASTM D4318 (ASTM International, 2017). The liquid limit (LL) was determined using the fall-cone method in accordance with ISO 17892-12:2018 (ISO, 2018), based on at least four moisture states covering cone penetrations of approximately 12–30 mm, with LL interpolated at 20 mm penetration. Moisture contents were determined by oven-drying. The plastic limit (PL) was obtained by rolling soil threads to a diameter of 3.2 mm until crumbling, and the plasticity index (PI) was calculated by using Eq. (1).

$$PI = LL - PL \tag{1}$$

2.4 Standard Proctor Compaction

Standard Proctor compaction tests were performed in accordance with ASTM D698 (ASTM International, 2021) to determine the compaction characteristics of untreated and sawdust-treated clay. Approximately 3.0 kg of soil mixture was compacted per test point in a standard mold in three layers, each receiving 27 blows from a 2.5 kg rammer. A moisture sweeps of 5–7 points, with water content increments of approximately 1–2%, was conducted until a reduction in dry density was observed on the wet side of the curve. After trimming flush, the mass of the compacted specimen was recorded, and a representative sample was taken for moisture content determination to establish the maximum dry density and optimum moisture content.

3. Result and discussion

3.1 Atterberg Limits

Table 1 and Figure 1 show the addition of 5% raw sawdust (sawdust-modified soil). The Atterberg limits of the control soil and the raw sawdust (sawdust-modified soil) soil were determined using the British Standard cone penetration method, in which the liquid limit (LL) is defined as the water content corresponding to a cone penetration of 20 mm (British Standards Institution, 2010). The control soil exhibited a liquid limit of 66.5% and a plastic limit of 27.98%, resulting in a plasticity index (PI) of 38.52%, whereas the sawdust-modified soil showed a markedly higher liquid limit of 107% and a plastic limit of 52.59%, yielding a plasticity index of 54.41%, as observed from the combined Atterberg limits graph. The substantial increase in both LL and PL following sawdust incorporation indicates that significantly higher moisture contents are required for the treated soil to reach equivalent consistency states, which is characteristic of soils containing organic or fibrous materials, as stated by Mitchell & Soga [21]. A previous study by Muntohar [22] stated that this behavior can be attributed to the lignocellulosic nature of sawdust, which possesses a porous internal structure and hydrophilic surface properties that enhance water absorption and retention within the soil matrix. The increase in effective surface area and bound water associated with organic inclusions leads to elevated consistency limits, as reported in studies on soils with increased organic matter content by Mitchell & Soga [21] and Sabtan [23]. In addition, Horpibulsuk *et al.,*[24] found that the presence of fibrous particles alters the soil fabric through particle interlocking and microstructural rearrangement, thereby increasing penetration resistance and shifting the penetration–water content relationship upward. Similar increases in liquid limit and plasticity index have been reported for soils treated with sawdust, sawdust ash, and other biomass-derived additives, although the magnitude of change depends on soil mineralogy, additive form, and dosage. From an engineering perspective, the higher LL and PI values indicate increased moisture sensitivity and a wider range of plastic behavior, which may influence workability, compaction characteristics, and deformation behavior under wet conditions. In terms of sustainability, the use of sawdust as a soil modifier represents a value-added reuse of an abundant agricultural and industrial waste material, contributing to waste reduction, resource efficiency, and the promotion of circular economy principles in geotechnical engineering applications. However, while the index property changes demonstrate a clear influence of sawdust on soil consistency, additional mechanical and volumetric tests such as compaction, strength, and compressibility assessments are required to fully evaluate the long-term performance and sustainability of sawdust-modified soils in engineering practice.

Table 1
The Atterberg Limits test results for the control soil and Sawdust -Modified Soil

Parameter	Control Soil	Sawdust -Modified Soil (5% Sawdust)
Liquid Limit (LL) (%)	66.50	107.00
Plastic Limit (PL) (%)	27.98	52.59
Plasticity Index (PI) (%)	38.52	54.41

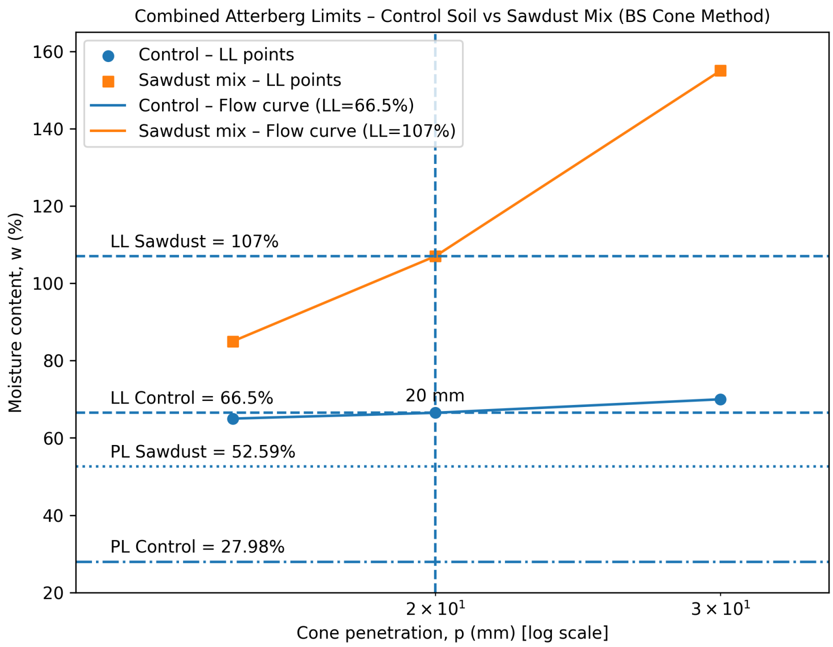

Fig. 1. Comparison of control soil and Sawdust -Modified Soil

3.2 Compaction Characteristics

Figure 2 below shows the combined compaction curves indicate that the incorporation of sawdust significantly modifies the soil's compaction behavior by reducing the maximum dry density from approximately 1.36 g/cm³ for the control soil to about 1.15 g/cm³ for the treated soil, which is primarily attributed to the lower specific gravity and lightweight nature of organic additives such as sawdust, as stated by Holtz *et al.,* [25]. The observed increase in optimum moisture content from around 15.5% to approximately 23% reflects the high-water absorption capacity and hygroscopic characteristics of sawdust, requiring additional moisture to achieve effective particle lubrication during compaction, the same as the previous study done by Das & Sobhan [26]. According to the study by Mitchell & Soga [16], this shift in compaction characteristics is consistent with Atterberg limit behavior, where the addition of organic or fibrous waste materials typically leads to an increase in liquid limit due to enhanced water retention and a more diffuse double layer structure. Craig [27] said that the higher liquid limit and plastic limit values associated with sawdust-treated soil indicate increased soil plasticity and compressibility, which correlate with the reduced dry density observed in the compaction test. From a geotechnical perspective, Muntohar & Hashim [28] stated that these changes suggest that sawdust-modified soil is less suitable for heavily loaded structural applications but may perform adequately for lightweight fills, embankments, and subgrade layers where reduced unit weight and improved sustainability are advantageous. Furthermore, the utilization of sawdust as a soil modifier supports sustainable construction practices by valorizing biomass waste, reducing landfill disposal, and lowering the environmental footprint of ground improvement works, as mentioned in a previous study by Kua *et al.,*[29]. In general, our results are in line with what other studies have found: Raw sawdust increases the material's moisture requirements and makes it more difficult to achieve higher densities. If the goal is to have a higher density and reduced plasticity, ash-based or polymer/ionic stabilizers perform better after curing.

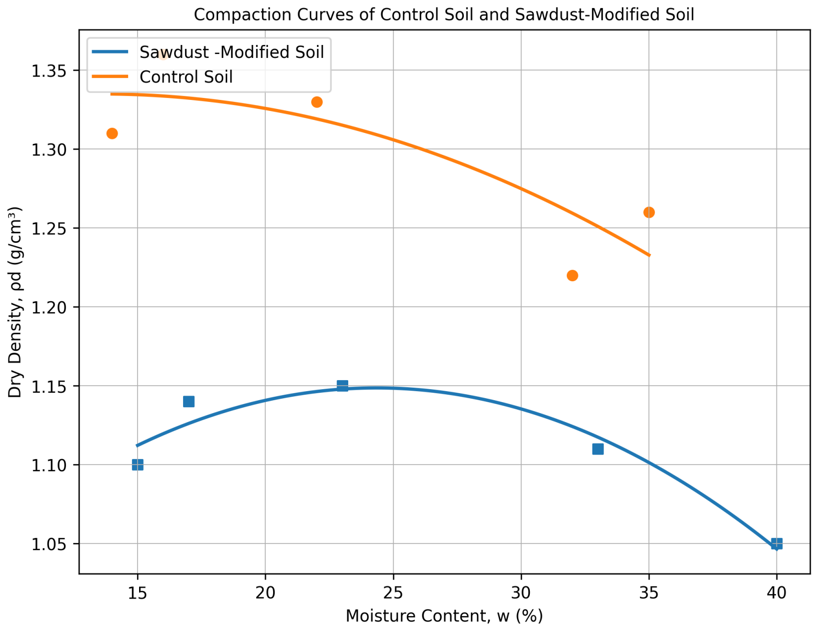

Fig. 2. Compaction Curve for control sample and treated soil

4. Conclusion

The goal of this research was to determine how adding raw sawdust to a locally available clay affected its density and packability. The discussion focused on how this clay could be used in sustainable subgrade engineering. The experiment yields many relevant conclusions. The addition of 5% raw sawdust improved the clay soil's liquid limit, plastic limit, and flexibility index. The increase marked a significant shift in how the soil reacted. This reaction is linked to the fact that sawdust is hygroscopic and flexible, which means it absorbs more water and alters soil structure by allowing water and particles to bind together more easily. The enhanced flexibility observed indicates that the treated soil is more sensitive to water and has a larger range of plasticity than the control sample. The findings of compacting soil revealed that sawdust altered how it behaved, with the highest dry density decreasing and the optimal moisture content increasing. The majority of these changes are caused by sawdust's low specific gravity and high capacity to absorb water, which reduces the density that may be achieved while increasing the amount of water needed when the material is compacted. The fact that Atterberg limits and compaction trends remain stable over time demonstrates the strong relationship between water retention mechanism and density response in sawdust modified clay. Technically, because raw sawdust-modified clay has a lower dry density and greater flexibility, it should not be used in applications that require it to be extremely stiff and load-bearing. However, it could be employed in lightweight fills, embankments, and subgrade layers that are moderately to lightly loaded and require lower unit weight, greater workability, and long-term durability. Overall, the findings indicate that raw sawdust can be an effective low-carbon soil enhancer, with a significant impact on index and compaction properties. However, it lacks the chemical stability that ash-based or cementitious binders offer. The study emphasizes the importance of carefully controlling the amount and ensuring that the design is appropriate when employing organic waste to improve soil. To promote the utilization of these materials in sustainable geotechnical practices, further research is necessary to investigate their strength development, compressibility, durability under varying wet and dry conditions, and their life-cycle performance in comparison to conventional stabilizers.

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References
[1] Agaiby, S. S., Hassan, A. W., Dakhli, A. H., & Elhakim, A. F. (2022). Sawdust effect on compressibility and shear strength characteristics of highly organic clay. *Engineering Research Journal*, 45(3), 383–386.

[2] Rashidi, A., Ahmad, R., & Hussin, A. R. (2020). Optimization of Atterberg limits of treated expansive soils with sawdust ash, crumb rubber, and sawdust. Journal of Cleaner Production, 270, 122413. https://doi.org/10.1016/j.jclepro.2020.122413

[3] Elahi, T. E., Shahriar, A. R., Alam, M. K., & Abedin, M. Z. (2020). Effectiveness of saw dust ash and cement for fabrication of compressed stabilized earth blocks. *Construction and Building Materials*, 259, 120568.**DOI:** https://doi.org/10.1016/j.conbuildmat.2020.120568

[4] Fawaz, A., Alhakim, G., & Jaber, L. (2024). The stabilisation of clayey soil by using sawdust and sawdust ash. *Environmental Technology*. https://doi.org/10.1080/09593330.2024.2304674

[5] Anuar, N. H. H. M., Hasbollah, D. Z. A., & Zukri, A. (2024). Stabilizing peat soil using sawdust ash. Smart and Green Materials, 1(1), 1–12.DOI: https://doi.org/10.70028/sgm.v1i1.2

[6] Blayi, R. A., Omer, B., Sherwani, A. F. H., Hamadamin, R. M., & Muhammed, H. K. (2024). Geotechnical characteristics of fine-grained soil with wood ash. *Cleaner Engineering and Technology*, *18*, 100726. https://doi.org/10.1016/j.clet.2024.100726

[7] Govindasamy, K., Subramaniam, S., Gobena, J. A., et al. (2020). Optimization of Atterberg limits of treated expansive soils with Taguchi method. Materials Today: Proceedings, 27, 122–131. DOI: https://doi.org/10.1016/j.matpr.2020.11.894

[8] Mohamed, A. M., Abd Elaty, M. A., & Abd Elaziz, M. A. (2021). Engineering properties of stabilized clay using biomass ash. Environmental Science and Pollution Research, 28, 45310–45325. DOI: https://doi.org/10.1007/s11356-021-13848-2

[9] Cazier, M., Morel, J. C., & Beckett, C. (2018). Hygrothermal and mechanical behavior of earth bricks reinforced with plant aggregates. Construction and Building Materials, 168, 409–420. DOI: https://doi.org/10.1016/j.conbuildmat.2018.02.129

[10] Kossi, M. A., Amouzou, K. E., & Koffi, A. M. (2020). Effect of sawdust addition on the compaction and consistency of clay soils. Innovative Infrastructure Solutions, 5, 48. DOI: https://doi.org/10.1007/s41062-020-00297-1

[11] Fadele, O. A., Oluwafemi, A. O., & Ajayi, O. A. (2018). Effects of sawdust ash on the geotechnical properties of lateritic soil. *International Journal of Civil Engineering and Technology*, *9*(9), 138–146.

[12] Ekinci, A., Yilmaz, Y., & Ercan, H. E. (2020). Utilization of wood ash in soil stabilization: Effects on compaction, strength and plasticity characteristics. *Construction and Building Materials*, *252*, 119060. https://doi.org/10.1016/j.conbuildmat.2020.119060

[13] Ercan, H. E., Ekinci, A., & Yilmaz, Y. (2021). Environmental and mechanical assessment of biomass ash stabilized soils: Heavy metal immobilization and leaching behavior. Journal of Cleaner Production, 318, 128507. https://doi.org/10.1016/j.jclepro.2021.128507

[14] Ikeagwuani, C. C., & Nwonu, D. C. (2019). Emerging trends in expansive soil stabilisation: A review. *Journal of Rock Mechanics and Geotechnical Engineering*, *11*(2), 423–440. https://doi.org/10.1016/j.jrmge.2018.08.013

[15] Nath, B. D., Sarkar, G., Siddiqua, S., Rokunuzzaman, M., & Islam, M. R. (2018). Geotechnical properties of wood ash-based composite fine-grained soil. *Advances in Civil Engineering*, *2018*, 9456019. https://doi.org/10.1155/2018/9456019

[16] Emeh, C., & Igwe, O. (2016). The combined effect of wood ash and lime on the engineering properties of expansive soils. *International Journal of Geotechnical Engineering*, *10*(5), 479–488. https://doi.org/10.1080/19386362.2015.1125412

[17] Karim, H., Al-Recaby, M., & Nsaif, M. (2018). Stabilization of soft clayey soils with sawdust ashes. *MATEC Web of Conferences*, *162*, 01006. https://doi.org/10.1051/matecconf/201816201006

[18] Abu Zeid, M. M. (2020). Influence of the sawdust on the behavior of clay soils. *American Journal of Materials Engineering and Technology*, *8*(1), 1–8. https://doi.org/10.12691/materials-8-1-1

[19] Chinkhuntha, W., Owayo, A., & Ambassah, N. (2024). *Performance Evaluation of Red Clay Soils stabilized with Bluegum Sawdust Ash and Sisal Fiber as Low-Volume Road Sub-base Materials.* Engineering, Technology & Applied Science Research, 14(6), 18105–18113. https://doi.org/10.48084/etasr.8772

[20] Iliyas, S., Idris, A., Umar, I. H., Lin, H., Muhammad, A., & Xie, L. (2024). Experiment and analysis of variance for stabilizing fine-grained soils with cement and sawdust ash as liner materials. *Materials*,17(10),2397.https://doi.org/10.3390/ma17102397

[21] Mitchell, J. K., & Soga, K. (2005). Fundamentals of soil behavior (3rd ed.). Hoboken, NJ: John Wiley & Sons.

[22] Muntohar, A. S. (2002). Utilization of uncontrolled burnt rice husk ash in soil improvement. *Civil Engineering Dimension*, *4*(2), 100–105.

[23] Sabtan, A. A. (2005). Geotechnical properties of expansive clay shale stabilized with lime. Geotechnical and Geological Engineering, 23, 415–430.DOI: https://doi.org/10.1007/s10706-004-3804-1

[24] 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.**DOI:** https://doi.org/10.3208/sandf.49.85

[25] Holtz, R.D., Kovacs, W.D., & Sheahan, T.C. (2011). An Introduction to Geotechnical Engineering. Pearson.

[26] Das, B.M., & Sobhan, K. (2014). Principles of Geotechnical Engineering. Cengage Learning.

[27] Craig, R.F. (2012). Craig's Soil Mechanics. CRC Press.

[28] Muntohar, A. S., & Hashim, R. (2017). Effects of organic waste additives on soil engineering properties. Construction and Building Materials, 140, 410–417.DOI: https://doi.org/10.1016/j.conbuildmat.2017.02.078

[29] Kua, H. W., Lee, S. E., & Leong, K. S. (2016). Sustainable construction materials and waste utilisation. Journal of Cleaner Production, 112, 388–400.DOI: https://doi.org/10.1016/j.jclepro.2015.07.041