ESIC2024 Posted: 19/06/2024

Effect of Sawdust Powder on the Geotechnical Properties of a Clayey

Carlos J. Medina-Martínez, Boris A. Medina-Salgado, Jhon Jairo Feria-Diaz*

Facultad de Ingeniería, Universidad de Sucre, Colombia.
Email: jhon.feria@unisucre.edu.co

Abstracts

Civil engineers avoid expansive clayey soils in their projects because of the issues and additional expenses caused by volume changes when moisture levels fluctuate. Although techniques exist to enhance their engineering characteristics, these methods are typically costly and environmentally detrimental. These factors, coupled with the increasing shortage of suitable construction soils, have prompted geotechnical researchers to explore recycled materials as soil-reinforcement additives, aiming for a more eco-friendly and economically viable approach. In this context, utilizing certain biowaste to improve soil engineering properties has emerged as an ecologically acceptable geotechnical solution. Sawdust, a globally abundant wood industry by-product, is one such biomaterial. This study presents findings on how the addition of sawdust affects the engineering properties of highly clayey soils. This study investigated the changes in the plasticity, specific gravity, permeability, compaction, and unconfined compressive strength of CH-classified clayey soil (Unified Soil Classification System) with varying percentages (0.0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, and 10.5%) of oak sawdust (Tabebuia Rosea). The results indicate that increasing the sawdust percentage leads to decreased plasticity, specific gravity, maximum dry unit weight, and unconfined compressive strength while simultaneously increasing the optimum moisture content and permeability.

Keywords: expansive soils, soil reinforcement, natural fibers, sawdust powder.

1. Introduction

Expansive soils, among the most prevalent materials in the Earth’s crust, are characterized by significant volume changes in response to moisture fluctuations. This instability leads to substantial deformation and structural damage, resulting in considerable project cost overruns [1-3]. Modern geotechnical engineering offers various techniques for enhancing the engineering properties of soils [4,5]. The most common approach involves stabilization using cementing agents, such as cement and lime [6], which effectively reduces volumetric changes [1,7]. However, in recent years, there has been a growing interest in eco-friendly and cost-effective alternatives. These include stabilizing agents derived from natural or synthetic materials, often comprising industrial waste products [8,9] such as natural fibers [10,11]. This approach may be particularly beneficial for developing nations [12]. Current research has explored the use of natural materials and agricultural byproducts to improve expansive soil properties [1,10,11].

Examples include rice husks [13], sugarcane bagasse [14], sisal [15], jute [16], hay [17], coconut shells [18], and corn [19]. This soil improvement technique is founded in concepts and principles initially investigated by engineer and architect Henry Vidal in 1969 [20].

Sawdust, a prevalent biomaterial worldwide, is the primary by product of the timber industry [21,22]. Its improper disposal in open-air dumps is common, leading to significant environmental issues owing to incineration and greenhouse gas emissions [23,24]. Utilizing sawdust to enhance soil engineering properties presents a viable eco-friendly alternative, as it requires less energy for production and application than synthetic materials [20,25]. Moreover, sawdust can undergo chemical reactions with water to produce compounds that may improve soil strength and compressibility [26]. This study examined the potential use of sawdust from Tabebuia Rosea wood species as an additive to enhance the engineering properties of highly plastic and expansive soils.

2. Materials and test method

2.1 Soil

The expansive soil utilized in this study originated from quarries in Sincelejo, Colombia, where a company extracts clayey materials for manufacturing ceramic construction elements. Samples were collected from an open-air excavation at a depth of 2.0 meters below ground level. After transportation to the laboratory, the expansive clayey soil was air-dried until a constant mass was reached, followed by pulverization. Subsequently, the material was subjected to a series of laboratory tests to determine its physical and mechanical properties. The particle size distribution of the examined soils is shown in Fig. 1.

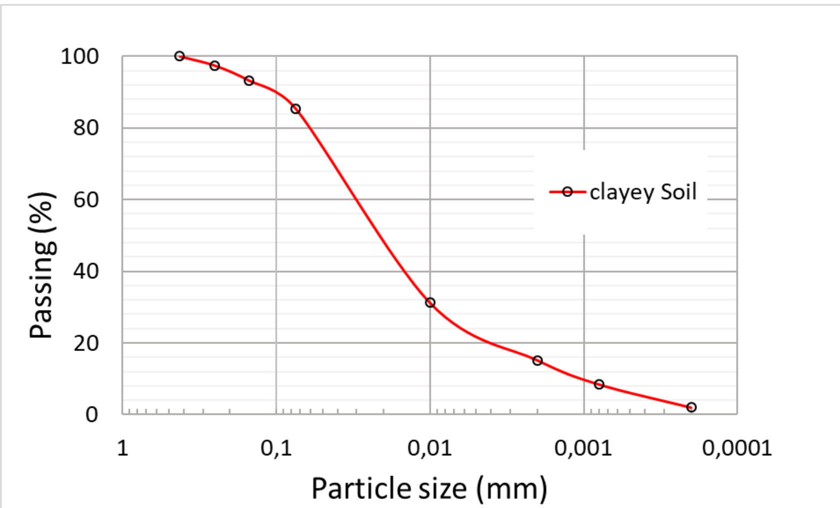

Figure 1. Particle size distribution of expansive soil

Particle size analysis revealed that the material was classified as fine soil, with 85.5% of the particles passing through sieve No. 200 (0.075 mm). According to the unified soil classification system, this composition indicates a high-plasticity inorganic clay (CH). Additionally, Table 1 presents several physical characteristics of the soil under investigation.

Table 1. Characteristics of expansive Clay Soil

Property	Value
Liquid limit (%)	64.04
Plastic limit (%)	24.04
Plasticity index (%)	40.0
Specific gravity	2.62
Permeability coefficient (cm/s)	$2x10^{-7}$
Maximum dry unit weight (KN/m^3)	17.65
Optimum moisture content (%)	10.2
Unconfined compressive strength (KN/m^2)	11.864
Cohesion (KN/m^2)	5.932
Particle size distribution	
Sand (%)	14.5
Silt (%)	67.0
Clay (%)	18.5
Unified Soil Classification	CH
AASHTO Classification	A-7-6(40)

2.2 Sawdust powder

Tabebuia Rosea sawdust powder (SP) was sourced from a furniture factory sawmill in Sampues, Sucre Department, Colombia. This particular wood species was selected because of its widespread use in the furniture and handicraft industries of the region, making it readily available and cost-effective. The SP underwent a cleaning process using clean tap water to eliminate excess dust and potentially soluble contaminants, followed by air drying at ambient temperature until a stable mass was reached. The research utilized only particles smaller than the 2.0 mm opening of sieve No. 10. The wood species employed in this study and their particle size distributions are shown in Fig. 2.

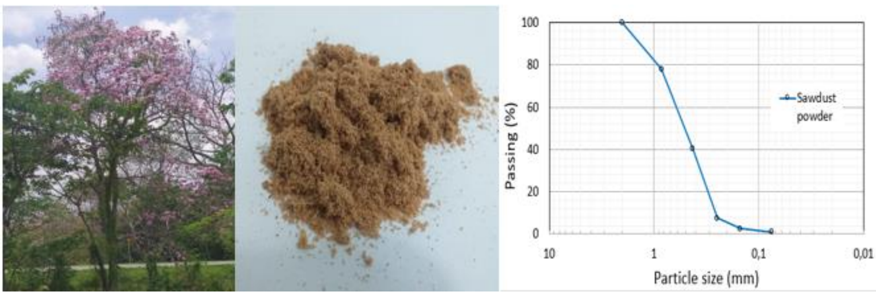

Figure 2. Oak Tree (Tabebuia Rosea), Oak SP and particle size distribution of Oak SD

The physical properties of the oak sawdust used in this study are presented in Table 2, which displays the measured values for the various characteristics.

Table 2. Physical properties of Oak Sawdust Powder

Items	Sawdust Powder
Particle size	<2.0mm
Bulk density (g/cm^3)	0.22
Specific gravity	1.15
Natural moisture content (%)	8.25
Colour	Light brown

2.3 Preparation samples

Before conducting various laboratory experiments (including Atterberg limits, specific gravity, compaction, permeability, and unconfined compressive strength), samples were prepared by incorporating different amounts of oak sawdust powder into dry expansive soil. The quantities used were 0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, and 10.5% of the dry weight of the soil (Table 3).

Table 3. Mixtures of expansive soil and Oak Sawdust Powder

Samples	Expansive soil (%)	Oak Sawdust Powder (%)	Total (%)
M1	100.0	-	100
M2	98.5	1.5	100
M3	97.0	3.0	100
M4	95.5	4.5	100
M5	94.0	6.0	100
M6	92.5	7.5	100
M7	91.0	9.0	100
M8	89.5	10.5	100

For the permeability and unconfined compressive strength tests, various dry mixtures were combined with water at the optimum moisture content, as determined by the compaction test, to achieve maximum densification. The blending of soil, sawdust, and water was performed manually to ensure uniform mixing for each experiment. Care was taken to maintain consistency throughout the mixing process.

3 Results and discussion

3.1 Chemical and mineralogical composition

X-ray diffraction analysis was used to determine the chemical composition of the soil. Table 4 presents the results of the analysis ended.

Table 4. Mineralogical and Chemical Composition of the clay Soil

		Values
Chemical Composition (%)	SiO_2	70.45
	Al_2O_3	14.35
	Fe_2O_3	8.6
	CaO	0.9
	MgO	0.4
	K_2O	1.6
	Na_2O	2.5
	LOI	1.2

Mineralogical Composition (%)	Kaolinite	27.5
	Quartz	23.6
	Mica	42.1
	Rutile	4.5
	Hematite	2.3

Analysis of the collected data revealed that the primary oxide components of the soil were silica (SiO_2) and alumina (Al_2O_3), with mica, kaolinite, and quartz being the dominant mineral constituents.

3.2 Effect of Sawdust powder on the Consistency Limits of the Soil

Figure 3 demonstrates how the Atterberg limits of clayey soil change with the introduction of sawdust. The graph reveals that, as the percentage of sawdust increased, the plasticity of the soil (measured by the Plasticity Index) decreased. Additionally, the figure shows that both the liquid and plastic limits of the soil decreased as more sawdust was added to the mixture.

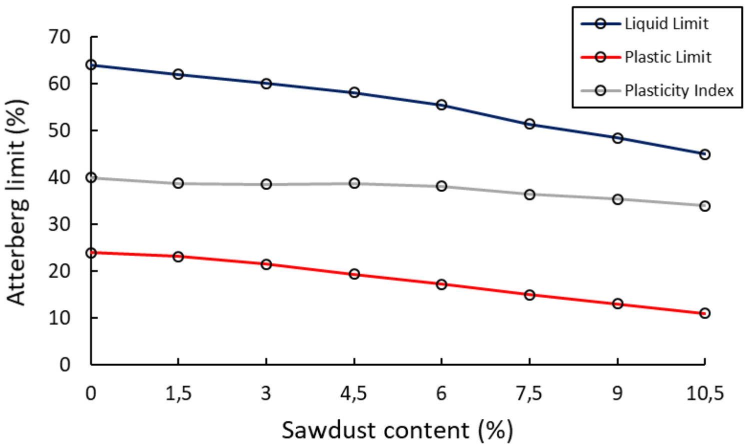

Figure 3. Variation of Atterberg limits of the clay with sawdust

3.3 Effect of Sawdust powder on specific gravity

Figure 4 demonstrates the relationship between the addition of sawdust and the specific gravity of the clay. The graph indicates an inverse correlation, in which the specific gravity of the soil diminishes as the percentage of sawdust increases.

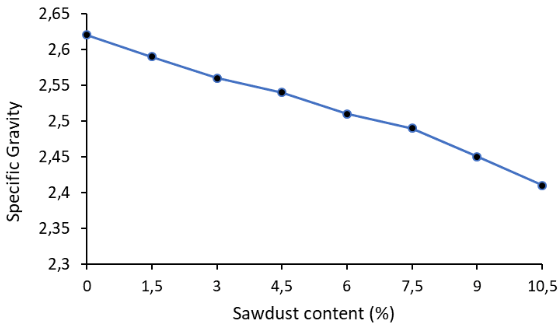

Figure 4. Variation of specific Gravity of the clay with sawdust

This trend can be attributed to the difference in the specific gravity between the two materials. Oak sawdust has a specific gravity of 1.15, whereas soil has a higher value of 2.62. Consequently, when sawdust partially substitutes for soil, the resulting mixture exhibits a lower specific gravity than the original soil composition.

3.4 Effect of Sawdust powder on the Modified Proctor Test (compaction)

Figure 5 illustrates how the soil characteristics changed during compaction and when the sawdust powder was introduced. The graph depicts the relationship between the optimum moisture content (OMC) and maximum dry unit weight (MDUW) of the soil. As the proportion of sawdust powder increased, the data revealed a corresponding increase in the OMC of the soil, while simultaneously showing a decrease in its MDUW.

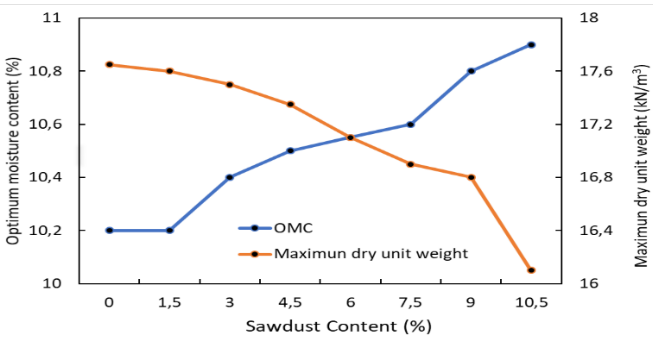

Figure 5. Variation of the compaction characteristics of the clay with sawdust

The greater amount of water required for optimal material compaction is attributed to the sawdust powder absorption of some of the added water. This requires more water for particle movement. The reduction in the dry unit weight of the soil when sawdust powder was added was primarily due to the lower specific gravity of sawdust compared to clay soil particles. Consequently, substituting a portion of the soil with lighter material results in a decreased dry unit weight of the combined mixture.

3.5 Effect of Sawdust powder on the unconfined strength of the soil

Figure 6 illustrates how the unconfined compressive strength of clay changes when sawdust powder is incorporated.

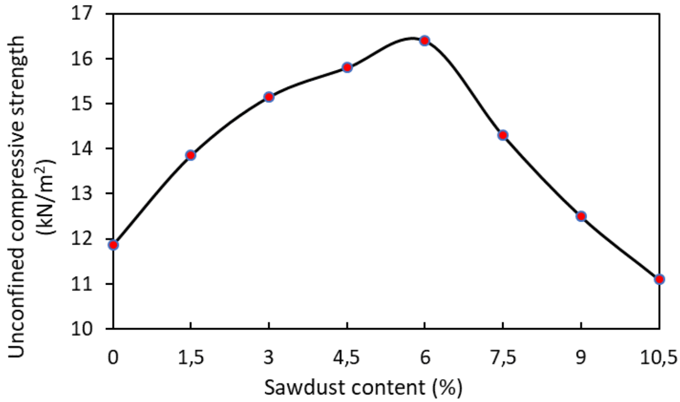

Figure 6. Variation of the UCS of the clay with sawdust

The findings indicate that the unconfined compressive strength (UCS) of the soil rises as the proportion of sawdust increases, starting from 11.864 kN/m^2 for soil without fibers and reaching 16.4 kN/m^2 with a 6.0% sawdust addition. Nevertheless, beyond this point, the UCS begins to decline, dropping to 11.1 kN/m^2 when the sawdust content reaches 10.5%. The initial UCS improvement can be explained by the coarse texture of sawdust, which enhances the friction between the soil particles. However, when the sawdust content surpassed 6.0%, it began to displace clay particles, thereby reducing the cohesion between the remaining clay particles and sawdust.

3.6 Influence of Sawdust on the Permeability of the Soil

Figure 7 illustrates how the permeability of the clay changes as the proportion of sawdust increases.

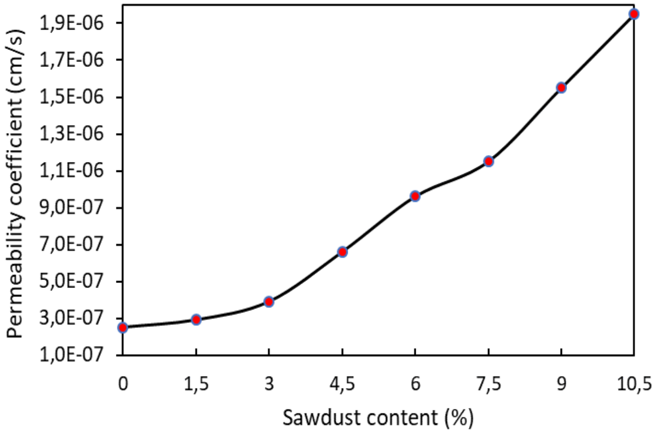

Figure 7. Variation of the permeability of the clay with sawdust

The research indicated that samples with higher concentrations of sawdust exhibited increased permeability, allowing water to pass through the soil-fiber mixture more easily. This phenomenon can be primarily explained by the expansion of permeable spaces between the soil particles as the proportion of sawdust increases.

4 Conclusions

Although the practice of reinforcing soil with fibers is not new, recent years have seen increased interest in researching and applying this technique for engineering purposes. This surge in attention is primarily due to the significant environmental impact of the growing volume of industrial waste fibers and their improper disposal.

Sawdust, a type of biowaste, possesses physical and mechanical properties comparable to those of many synthetic materials. This similarity suggests its potential use in various aspects of geotechnical engineering, such as in enhancing soil engineering properties. This study used oak sawdust as a stabilizing agent for expansive clay soil. The researchers analyzed the Effects of varying fiber addition percentages (0.0, 1.5, 3.0, 4.5, 6.0, 7.5, 9.5, and 10.5%) on the soil.

As the proportion of sawdust increases, the plasticity, specific gravity, and maximum dry unit weight (MDUW) of the soil decrease, while its optimum moisture content (OMC) and permeability increase. The unconfined compressive strength (USC) initially increased with increasing sawdust percentage, peaking at 6.0% addition, after which it declined with further fiber addition. These findings suggest that small amounts of sawdust fibers positively impact the soil bearing capacity, indicating that this bio-waste can enhance the geotechnical properties of clayey soils in terms of resistance. This effect can be attributed to the rough surface texture of the fiber, which increases the friction in the soil-fiber composite, thereby improving its strength.

Utilizing oak sawdust, a waste material, for soil stabilization may reduce costs due to its high availability and low price. The primary components of sawdust, lignin, and cellulose are environmentally benign. Although lignocellulosic fibers lack inherent cementing properties, they undergo chemical reactions when exposed to moisture, producing compounds that contribute to increased soil resistance.

WORKS CITED

Sun, S., Liu, B., & Wang, T. (2018). Improvement of expansive soil properties using sawdust. The Journal of Solid Waste Technology and Management. 44(1), 78-85. doi: 10.5276/JSWTM.2018.78.

Akinwumi, I. I., Ojuri, O. O., Ogbiye, S. A., & Booth, C. A. (2017). Engineering properties of tropical clay and bentonite modified with sawdust. Acta Geotechnica Slovenica, 14(2), 47-56.

Kalkan, E., & Yarbaşı, N. (2020). The Effects of Pine Tree Sawdust on the Volume Compressibility of Expansive Soils. International Journal of Science and Engineering Applications 10(04):029–033. doi: 10.7753/ijsea1004.1001.

Butt, WA, Gupta, K. y Jha, JN (2016). Strength Behavior of Clayey Soil Stabilized with Saw Dust Ash." International Journal of Geo-Engineering, 7 (1), 1-9. doi: 10.1186/s40703-016-0032-9.

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. doi: 10.1016/j.jrmge.2018.08.013.

Afrin, H. (2017). A review on different types soil stabilization techniques. International Journal of Transportation Engineering and Technology, 3(2), 19-24. doi: 10.11648/j.ijtet.20170302.12

Khan, A. N., Ansari, Y., Mahvi, S., Junaid, M., Iqbal, K. (2020). Different Soil Stabilization Techniques. International Journal of Advanced Science and Technology. 29(9). https://www.researchgate.net/publication/350630921

Jasim, O. H., & Çetin, D. (2016). Effect of sawdust usage on the shear strength behavior of clayey silt soil. Sigma Journal Engineering and Natural Sciences, 34(1), 31-41. https://www.researchgate.net/publication/299285436

Garg, R., Biswas, T., Alam, M. D., Kumar, A., Siddharth, A., & Singh, D. R. (2021, November). Stabilization of expansive soil by using industrial waste. In Journal of Physics: Conference Series (Vol. 2070, No. 1, p. 012238). IOP Publishing. doi:10.1088/1742-6596/2070/1/012238

Medina-Martinez, C.J.; Sandoval-Herazo, L.C.; Zamora-Castro, S.A.; Vivar-Ocampo, R.; Reyes-Gonzalez, D. (2022). Natural Fibers: An Alternative for the Reinforcement of Expansive Soils. Sustainability 2022, 14, 9275. https://doi.org/10.3390/su14159275

Mallakpour, S., Sirous, F., & Hussain, C. M. (2021). Sawdust, a versatile, inexpensive, readily available bio-waste: From mother earth to valuable materials for sustainable remediation technologies. Advances in Colloid and Interface Science, 295, 102492. https://doi.org/10.1016/j.cis.2021.102492

Vettorelo, P. V., & Clariá, J. J. (2014). Suelos Reforzados con Fibras: Estado del Arte y Aplicaciones. Revista Facultad de Ciencias Exactas, Físicas y Naturales 1(1):27–34.

Baldin, C. R. B., Kawanami, M. Y., Costa, W. G. S., Bordignon, V. R., da Luz, C. C., & dos Santos Izzo, R. L. (2023). Mechanical properties of a clay soil reinforced with rice husk under drained and undrained conditions. Journal of Rock Mechanics and Geotechnical Engineering, 15(10), 2676-2686. https://doi.org/10.1016/j.jrmge.2023.02.022

Adnan, M., Kumar, S., Garg, N., Gupta, K. K., & Das, S. K. (2023). Soil stabilization using waste "Bagasse ash and lime": A review. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.05.018

Yohanna, P., Johnson, P., Victor, B. P., Badamasi, A., Mije, F. G., Ako, T., & Bassey, A. B. (2022). Evaluation of geotechnical properties of black cotton soil reinforced with sisal fibre for waste containment application. Engineering Science & Technology, 151-168. https://doi.org/10.37256/est.3220221354

Kumar, S., Sahu, A. K., & Naval, S. (2020). Influence of jute fibre on CBR value of expansive soil. Civil Engineering Journal, 6(6), 1180-1194. http://dx.doi.org/10.28991/cej-2020-03091539

Aldaood, A., Khalil, A., Bouasker, M., & AL-Mukhtar, M. (2021). Experimental study on the mechanical behavior of cemented soil reinforced with straw fiber. Geotechnical and Geological Engineering, 39, 2985-3001.

Kaushik, D., & Singh, S. K. (2021). Use of coir fiber and analysis of geotechnical properties of soil. Materials Today: Proceedings, 47, 4418-4422. https://doi.org/10.1016/j.matpr.2021.05.255

Yong, L. L., & Emmanuel, E. (2022). Effects of corn starch and corn silk binary blends on the strength properties of a soft clay: a preliminary study. Journal of Natural Fibers, 19(13), 4791-4805. https://doi.org/10.1080/15440478.2020.1870627

Gowthaman, S., Nakashima, K., & Kawasaki, S. (2018). A state-of-the-art review on soil reinforcement technology using natural plant fiber materials: Past findings, present trends and future directions. Materials, 11(4). doi: 10.3390/ma11040553

Karim, H., Al-Recaby, M., & Nsaif, M. (2018). Stabilization of soft clayey soils with sawdust ashes. In MATEC Web of Conferences (Vol. 162, p. 01006). EDP Sciences. https://doi.org/10.1051/matecconf/201816201006

Hamzah, N., Yusof, N. A. M., & Rahimi, M. I. H. M. (2019). Assessment of compressive strength of peat soil with sawdust and Rice Husk Ash (RHA) with hydrated lime as additive. In MATEC Web of Conferences (Vol. 258, p. 01014). EDP Sciences. doi: 10.1051/matecconf/201925801014.

Owoyemi, O. O. (2021). Effect of Sawdust on the Geotechnical Properties of a Lateritic Soil. Journal of Mining and Geology, 57(1), 127-139. https://www.researchgate.net/publication/351094727

Mwango, A., & Kambole, C. (2019). Engineering Characteristics and Potential Increased Utilisation of Sawdust Composites in Construction—A Review. Journal of Building Construction and Planning Research, 7(3), 59-88. doi: 10.4236/jbcpr.2019.73005

Tong, Y., Seibou, A. O., Li, M., Kaci, A., & Ye, J. (2021). Bamboo Sawdust as a Partial Replacement of Cement for the Production of Sustainable Cementitious Materials. Crystals, 11(12), 1593. doi.org/10.3390/cryst11121593

Agaiby, S., Hassan, A. W., Dakhli, A. H., & Elhakim, A. (2022). Sawdust Effect on Compressibility and Shear Strength Characteristics of Highly Organic Clay. ERJ. Engineering Research Journal, 45(3), 379-387. https://dx.doi.org/10.21608/erjm.2022.127027.1151