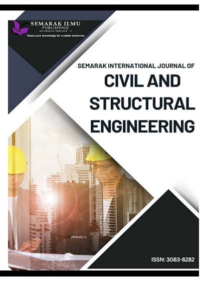
SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Semarak International Journal of Civil and Structural Engineering

Journal homepage:
https://semarakilmu.my/index.php/sijcse/index
ISSN: 3083-8282



Effects of Natural Fiber Reinforcement on Shear Strength and Compaction Properties of Sandy Soil

Hasmidar Hamsah[1,*], Jodin Makinda[1], Elsa Eka Putri[2]

[1] Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[2] Department of Civil Engineering, Faculty of Engineering, University of Andalas, Indonesia

ARTICLE INFO

Article history:
Received 15 August 2025
Received in revised form 29 August 2025
Accepted 15 September 2025
Available online 28 October 2025

Keywords:
Natural fiber reinforcement; sandy soil; shear strength; soil compaction; sustainable materials

ABSTRACT

Sandy soil is widely found in various construction sites, including in Sabah. However, its engineering performance is often inadequate due to low cohesion, high permeability, and limited load-bearing capacity. These properties make it unstable and unsuitable for supporting structural loads without improvement. Conventional soil stabilization techniques often rely on chemical additives or synthetic materials, which are costly and may have negative environmental impacts. This study explores the use of natural fiber reinforcement, specifically sugarcane bagasse and corn husk fibers, as a sustainable and cost-effective alternative to improve the compaction and shear strength of sandy soil. Sandy soil samples collected from Kinarut, Sabah, were reinforced with 1%, 2%, and 3% sugarcane bagasse and corn husk fibers by dry weight. Standard Proctor compaction tests were conducted to determine maximum dry density (MDD) and optimum water content (OWC), while direct shear tests were performed to evaluate cohesion and angle of internal friction. The results indicated that natural fibers significantly influenced soil properties depending on type and content. Corn husk fiber at 2% achieved the highest MDD (2009 kg/m³) and maximum friction angle (62.4°), while sugarcane bagasse fiber at 3% yielded the highest cohesion (1.72 kPa). These findings confirm that natural fibers can enhance the engineering properties of sandy soil, highlighting their potential as eco-friendly alternatives to conventional stabilizers for sustainable geotechnical applications.

1. Introduction

Sandy soils are widely used in construction, but they pose significant geotechnical challenges due to their weak engineering properties. According to Wei *et al.*, [1], sandy soils typically contain more than 50% sand with very little clay content, resulting in low interparticle cohesion and minimal natural bonding between particles. Sandy soil is defined as cohesionless soil or as frictional soil because there is no adhesion between their particles that are essential for stability. This lack of cohesion results in low shear strength, poor bearing capacity, high permeability, and minimal water retention, which pose substantial challenges for construction. High permeability, for instance, allows

* *Corresponding author.*
E-mail address: hasmidarhamsah@gmail.com

https://doi.org/10.37934/sijcse.7.1.111

water to flow through sandy soils easily, leading to potential drainage problems that can weaken foundations and contribute to instability, particularly during heavy rainfall or flooding. Moreover, sandy soils are prone to liquefaction, a sudden loss of soil strength under seismic activity, which can have major impacts on infrastructure.

Soil reinforcement is a widely used geotechnical technique designed to improve the mechanical properties of weak soil, making them more suitable for construction purposes. This process involves the incorporation of fibrous materials, either natural or synthetic, within the soil matrix to increase its strength, stability, and load-bearing capacity. The fibers, when uniformly mixed and distributed throughout the soil, create a composite material that significantly improves soil performance by resisting deformation, enhancing shear strength, and mitigating issues related to soil movement.

Synthetic fibers such as polypropylene and polyester have been widely utilized for soil reinforcement due to their durability and strength. However, growing environmental concerns have led to increased interest in natural fiber reinforcements, which are biodegradable, renewable, and often readily available as agricultural by-products. Natural fibers, including coconut coir, jute, sisal, and more recently, sugarcane bagasse and corn husk, have shown promising results in improving soil properties [1]. These fibers provide a sustainable and eco-friendly alternative to synthetic reinforcements, aligning with the global emphasis on green and sustainable construction practices.

Natural fibers such as sugarcane bagasse and corn husk have emerged as effective solutions for addressing these challenges in problematic soil. These fibers can improve key geotechnical properties, including increasing shear strength, enhancing bearing capacity, and reducing permeability. As agricultural by-products, sugarcane bagasse and corn husk fibers are not only biodegradable but also widely available, particularly in regions where sugarcane and corn are extensively cultivated. Utilizing these fibers for soil reinforcement offers a dual benefit which are improving the structural stability of sandy soils while reducing agricultural waste, supporting a circular economy, and promoting sustainable development goals.

Sugarcane bagasse and corn husk are readily available in Malaysia as by-products of the agriculture sector. Their potential for soil improvement has not been fully explored, especially in sandy soils. According to Dang *et al.*, [2], adding sugarcane bagasse fibers (0.0%–2.0%) to expansive soil significantly improved compressive strength, particularly with longer curing times. In another study, Oderah and Kalumba [3] reported that bagasse fibers enhanced the strength and stiffness of sandy soil, with the best results at 1.4% fiber content, and also noted that finer-grained soils responded better depending on fiber type and vertical load. Similarly, Roy and Mukherjee [4] investigated the effect of corn husk fibers on oil-contaminated soil and found that fiber inclusion improved strength and compaction behavior. Singh and Sharma [5] further demonstrated that adding corn husk fibers with stone dust to silty soil increased CBR values and optimum moisture content while reducing maximum dry density. These studies confirm the potential of sugarcane bagasse and corn husk fibers in enhancing soil strength and compaction characteristics, though results vary depending on soil type, fiber type, and content.

However, no study has yet provided a direct comparison between sugarcane bagasse and corn husk fibers for sandy soil under the same experimental conditions. This research gap highlights the need to evaluate how both fibers influence compaction behavior (maximum dry density and optimum water content) and shear strength parameters (cohesion and angle of friction). The objective of this study is therefore to evaluate the effects of sugarcane bagasse and corn husk fibers on the maximum dry density and optimum water content of sandy soil, the shear strength parameters (cohesion and angle of friction), and to determine the optimum fiber content for effective soil reinforcement. The significance of this research lies in its contribution to eco-friendly and cost-effective soil stabilization methods, which can support sustainable construction practices, particularly in rural and resource-limited areas.

2. Methodology

2.1 Materials

2.1.1 Soil

The soil sample that was used in this study was sand collected from the riverbank at Kinarut, Sabah. There were numerous test were carried out on the soil sample. The soil used is classified as silty sand (SM) according to the Unified soil classification system (USCS). The basic mechanical and geotechnical properties of the sandy soil used in this study are summarized in Table 1.

Table 1
Mechanical properties of sandy soil

Soil Properties	Value
USCS Classification	SM
Specific Gravity, G_s	2.65
pH Test	6.0
Natural Moisture Content, %	26.36
LL, %	27.08
PL, %	23.36
Plasticity Index, I_p = LL - PL	3.72
Optimum Water Content (OWC), %	18.00
Maximum Dry Density (MDD), kg/m^3	1990

2.1.2 Natural fibers

The sugarcane bagasse fibers used in this study was obtained from night market at Teluk Likas. The sugarcane bagasse fibers used in the experiment have an average width of approximately 0.5 cm and a length of 5 cm. Its specific gravity is 0.66, which is significantly lower than that of soil (2.65), indicating that the fiber is relatively light. The moisture content of the fibers is high which were 65.02%. Figure 1 illustrate the physical appearance of the sugarcane bagasse fiber that used in this study. Table 2 summarize the key physical properties of the fibers.

Fig. 1. Sugarcane bagasse fibers

Table 2
Properties of sugarcane bagasse fibers

Width	0.5 cm
Length	5 cm
Specific Gravity	0.66
Moisture Content	65.02 %

The corn husk fibers used in this study was obtained from night market at Teluk Likas.The corn husk fibers used in the experiment have an average width of 1 cm and a length of 3 cm. It has an even lower specific gravity of 0.31, making it the lighter of the two fibers. The moisture content is also higher which were 85.00%. Figure 2 illustrate the physical appearance of the sugarcane bagasse fiber that used in this study. Table 3 summarize the key physical properties of the fibers.

Fig. 2. Sugarcane bagasse fibers

Table 3
Properties of corn husk fibers

Width	1 cm
Length	3 cm
Specific Gravity	0.31
Moisture Content	85.00 %

2.2 Experimental Procedure
2.2.1 Standard proctor compaction test

Sugarcane bagasse and corn husk fibers were added to sandy soil at fiber contents of 1%, 2%, and 3% by the dry weight of the soil. All materials were prepared in an air-dried state, and particles larger than 20 mm were removed through sieving. The soil was checked to ensure it was free of stones, wood fragments, and clay lumps. The fibers and soil were manually mixed on a tray and spread out evenly for water mixing. Water was added gradually, ranging between 150–250 ml, or 5–10% of the soil's dry weight, and the mixture was blended thoroughly to achieve uniform moisture distribution. The soil-fiber mixture was divided into three equal parts and compacted into a standard Proctor mold using a 2.5 kg rammer dropped from a height of 300 mm. Each layer received 27 uniform blows. After each layer, the surface was scarified to prevent layering effects. The collar was then removed, and the surface was trimmed using a straightedge. The total weight of the mold with compacted soil was recorded. The sample was removed using an extruder and broken into loose pieces. The test was repeated by gradually adding more water until the dry density began to decrease. Water content was measured at each stage, especially around the peak point. All equipment was cleaned and stored after the test. The maximum dry density (MDD) and optimum water content (OWC) were obtained from the compaction curve for each fiber content.

2.2.2 Direct Shear box test

The shear box was assembled with spacing blocks, groove plates, and the top half fixed securely. The lower groove plate was placed transversely to the shear direction. The sample where the fibers and soil were manually mixed on a tray was compacted in the shear box using a tamper, ensuring dense packing with vertical blows. The top groove plate and loading platen were positioned, and the hanger was centered. The vertical and horizontal dial gauges were set, and a preload was applied to remove slack motion. Shear tests were conducted under three normal loads of 0 kg, 10 kg, and 20 kg, corresponding to vertical pressures of approximately 50 kPa, 100 kPa, and 150 kPa. The motor was run at a shearing rate of 1 mm/min, and readings from the proving ring and dial gauges were taken at 10–15 second intervals. The test continued until the proving ring reading showed a constant or decreasing trend, indicating sample failure. After the test, the equipment was cleaned, and the process was repeated for the remaining samples. A total of 24 direct shear tests were conducted to evaluate the influence of fiber type (sugarcane bagasse and corn husk) and fiber content (1%, 2%, and 3%) on the shear strength characteristics of sandy soil.

3. Results And Discussion

3.1 Effects of Natural Fiber On The Compaction Properties

3.1.1 Effect of sugarcane bagasse fiber on compaction

Figure 3 illustrates the compaction characteristics of soil mixed with varying percentages 0%, 1%, 2%, and 3% of sugarcane bagasse fibers, showing the relationship between optimum water content (OWC) and maximum dry density (MDD). For unreinforced soil (0%), the MDD is 1990 kg/m³ at an OWC of 18%. At 1% fiber, MDD drops slightly to 1950 kg/m³, and OWC rises to 18.9%. At 2%, MDD continues to decrease to 1880 kg/m³ with OWC increasing to 20%. At 3% fiber, MDD falls further to 1780 kg/m³ and OWC rises to 24%. This trend shows that adding more fibers increases the soil's moisture demand while reducing its ability to compact. The increase in OWC is due to the fibers absorbing more water, and the reduction in MDD at higher fiber contents is due to the disruption of soil particle arrangement by the lightweight and bulky fibers and adding more voids.

These results match findings by Moin and Qasim [6], who reported an increase in dry density at low fiber content (up to 0.6%) due to better particle bonding. However, when the fiber content exceeded 0.6%, dry density dropped sharply. At 1% fiber, dry density fell by 10% from the peak, mainly due to the low specific gravity and high water absorption capacity of the fibers, which increased the void ratio and reduced soil density. Therefore, too much fiber weakens compaction by disturbing the soil structure.

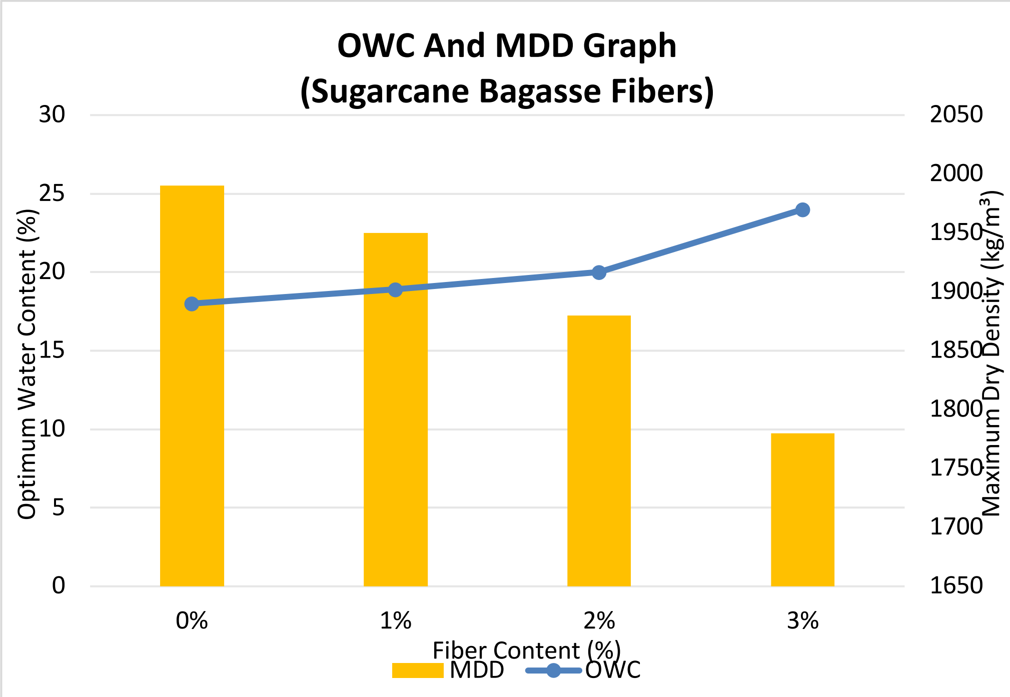


Fig. 3. Maximum dry density and optimum water content for different percentage of sugarcane bagasse fibers.

3.1.2 Effect of corn husk fiber on compaction

Figure 4 shows the compaction behavior of soil mixed with 0%, 1%, 2%, and 3% corn husk fibers, focusing on the relationship between optimum water content (OWC) and maximum dry density (MDD). For unreinforced soil (0% fiber), the MDD is 1990 kg/m³ at an OWC of 18%. With 1% fiber, the MDD slightly drops to 1960 kg/m³, and the OWC remains similar at 17.8%. At 2% fiber, the MDD increases to 2010 kg/m³, and OWC rises to 18%. At 3%, the MDD slightly reduces to 2000 kg/m³, with OWC increasing to 20%. This trend indicates that corn husk fibers increase moisture demand and slightly reduce compaction efficiency. The higher OWC is due to the fibers' water absorption while the lower MDD at higher fiber contents is likely caused by the fibers disrupting the soil structure and introducing more voids.

This pattern aligns with Roy and Mukherjee [4], who also found that OWC increases with higher fiber content. However, their study showed a continuous drop in MDD from 1% to 4%, while this study observed an MDD increase at 2% before decreasing at 3%. This difference may be due to variations in soil and fiber sizes. Roy and Mukherjee used several fiber sizes (1 cm × 1 cm to 4 cm × 1 cm), while this study used a fixed size of 3 cm × 1 cm. Still, both studies agree that natural fibers raise OWC and reduce MDD at higher contents. Similarly, Singh and Sharma [5] studied corn husk fibers mixed with 30% stone dust and found that increasing fiber content from 1% to 4%, with fiber lengths from 2 to 4 cm, increased OWC from 28% to 39% and reduced MDD from 1.86 g/cm³ to 1.75 g/cm³. These findings support the current results, confirming that corn husk fibers affect compaction by increasing moisture demand and lowering density due to their low specific gravity and water absorption. Overall, both the current and previous studies clearly show that adding corn husk fibers changes soil compaction characteristics, especially at higher contents.

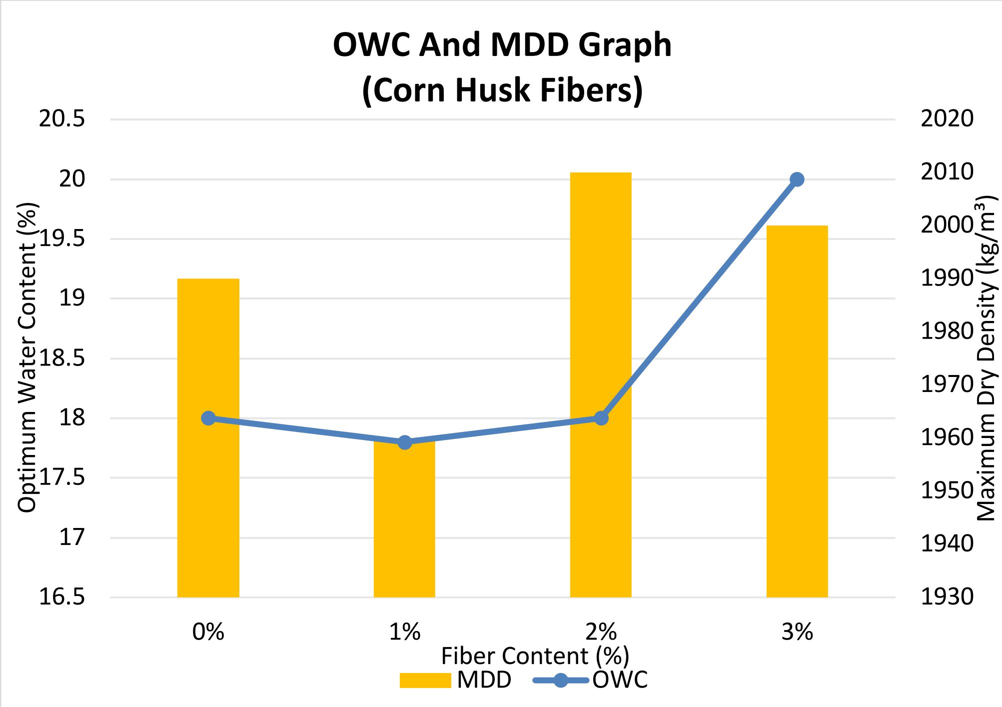


Fig. 4. Maximum dry density and optimum water content for different percentage of corn husk fibers

3.2 Effect of Natural Fiber on Shear Strength Parameters

3.2.1 Effect of sugarcane bagasse fiber on shear strength parameters

Figure 5 presents the variation in cohesion and angle of internal friction for soils reinforced with 0%, 1%, 2%, and 3% sugarcane bagasse fibers. The results demonstrate a non-linear trend in both shear strength parameters with increasing fiber content.

The cohesion (c) value initially decreases from 1.29 kPa (unreinforced) to 0.93 kPa at 1% fiber, likely due to early disturbance in particle bonding caused by the added fibers. However, cohesion improves to 1.00 kPa at 2% and reaches 1.72 kPa at 3% fiber. This rise is likely due to better interlocking between fibers and soil particles, particularly at higher displacements when fibers contribute more effectively to resisting shear. The angle of friction (φ) rises significantly from 36.7° at 0% to 51.9° at 1%, showing that a small amount of fiber boosts friction between particles. However, at 2% and 3%, angle of friction drops sharply to 39.2° and 36.3°, suggesting that too much fiber weakens the structure by disrupting particle contact and causing fiber clumping or segregation.

These results are in line with the study by Oderah and Kalumba [3], who found that sugarcane bagasse fiber increased the angle of friction up to 1.4% fiber content, with improvements from 32.8° to 41.6°. Beyond this point, fiber segregation reduced strength due to ineffective mobilization at the failure surface. Similarly, they observed that apparent cohesion also increased with fiber content, as fibers stretched across the failure plane and contributed to ductility and load transfer, reinforcing the soil structure. Both studies show that moderate fiber content improves shear strength due to better interaction between soil and fibers. But too much fiber can lead to issues like poor mixing and reduced efficiency. In this study, 1% fiber gave the best improvement in friction angle, while 3% gave the highest cohesion. Overall, sugarcane bagasse fibers can enhance soil shear strength, but using the right amount is key for successful soil reinforcement.

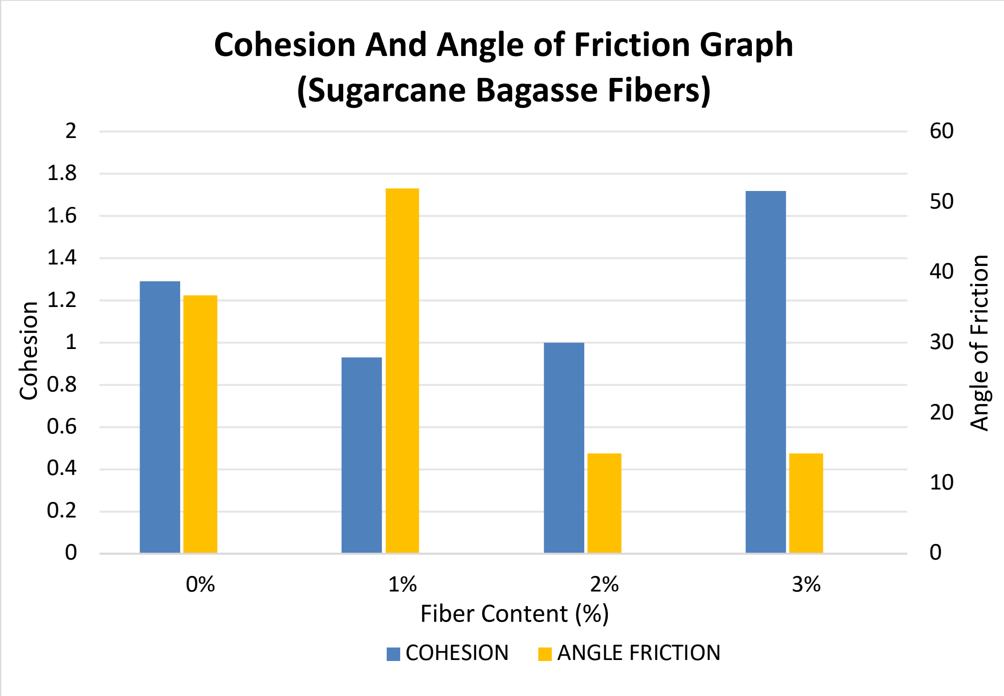


Fig. 5. Cohesion and angle of friction for different percentage of sugarcane bagasse fibers

3.2.2 Effect of corn husk fiber on compaction

Figure 6 presents the variation in cohesion and angle of internal friction for soils reinforced with 0%, 1%, 2%, and 3% corn husk fiber. The data shows a distinct non-linear trend in both parameters as fiber content increases.

The cohesion (c) value drops from 1.29 kPa (unreinforced) to 0.39 kPa at 1% corn husk fiber, suggesting that the early addition of fibers may disturb particle bonding or reduce soil compactness. However, cohesion improves at higher fiber contents rising to 0.97 kPa at 2% and reaching 2.43 kPa at 3%. This increase shows that a higher fiber quantity enhances fiber-soil interlocking and pull-out resistance, improving shear strength. The angle of friction (φ) increases sharply from 36.7° (0% fiber) to 54.5° at 1%, and reaches its peak at 62.4° with 2% fiber. This trend shows that moderate fiber content strengthens frictional contact between soil and fibers. However, at 3%, the friction angle drops to 39.3°, likely due to excess fiber causing poor distribution, reduced contact, and fiber clumping during mixing leading to weaker shear performance.

These findings align with Duong *et al.,* [7], who studied weak excavated soil reinforced with corn husk fibers in a fiber-cement stabilization method. They found that adding fibers (10 mm and 30 mm long) at various contents (0, 4, 8, 16 kg/m^3) significantly improved both compressive and shear strength. Compressive strength increased by 24.2% and 30.4%, and shear resistance improved as fiber content and length increased. The study confirmed corn husk fibers as effective, eco-friendly soil reinforcements. Both studies agree that moderate fiber addition improves shear strength due to better fiber-soil interaction. However, excessive fiber content can reduce performance due to poor mixing and fiber segregation. Therefore, selecting the right fiber content is essential for ensuring strong, durable, and sustainable reinforcement in geotechnical works.

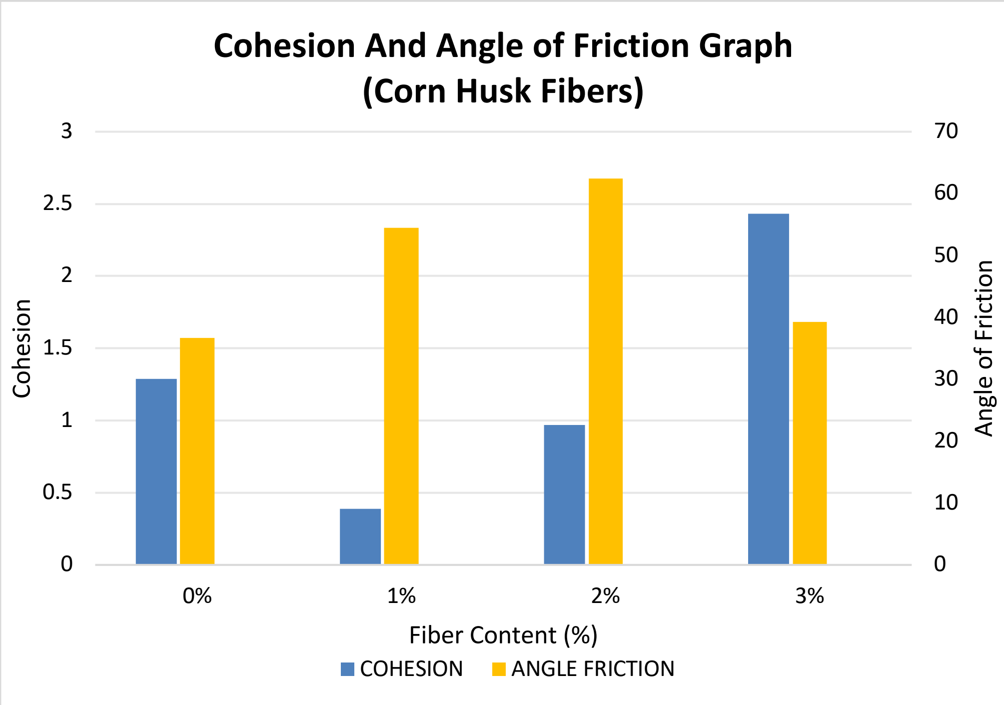


Fig. 6. Cohesion and angle of friction for different percentage of corn husk fibers

3.3 Determination of Optimum Natural Fiber Content

Table 4 summarizes the optimum fiber content for sugarcane bagasse and corn husk fibers based on maximum dry density (MDD), cohesion, and angle of friction. For sugarcane bagasse, 1% fiber gave the highest MDD and friction angle, indicating better compaction and interparticle resistance at this level. The highest cohesion was achieved at 3%, showing that higher fiber content helps improve bonding within the soil. For corn husk fiber, the highest MDD and angle of friction were recorded at 2%, likely due to its structural properties that enhance compaction and friction. Similar to bagasse, the highest cohesion was observed at 3%, suggesting improved shear strength at higher fiber content. In summary, 1–2% fiber content is more suitable for improving compaction and friction, while 3% is better for enhancing cohesion. Fiber content should be selected based on specific engineering needs.

Table 4
Optimum natural fiber content

Parameters	Sugarcane Bagasse Fiber	Corn Husk Fiber
MDD	1%	2%
Cohesion	3%	3%
Angle of friction	1%	2%

4. Conclusions

In this study, standard Proctor compaction and direct shear tests were conducted on sandy soil reinforced with sugarcane bagasse and corn husk fibers at fiber contents of 1%, 2%, and 3% by dry weight of the soil. The objective was to evaluate their effects on compaction characteristics (MDD and OWC) and shear strength parameters (cohesion and angle of internal friction). From the experimental results, the following conclusions can be drawn:

1. Adding sugarcane bagasse fibers consistently reduced the maximum dry density (MDD) and increased the optimum water content (OWC) as fiber content increased. This was due to the fibers' low specific gravity and high water absorption, which created more voids and increased moisture demand. On the other hand, corn husk fibers improved MDD up to 2% content before slightly decreasing at 3%, showing better compaction efficiency at moderate fiber levels.
2. For shear strength, sugarcane bagasse increased the friction angle from 36.7° to 51.9° at 1% but declined at higher contents. Cohesion increased steadily, peaking at 1.72 kPa at 3%. Corn husk fibers gave even better results—friction angle peaked at 62.4° at 2%, and cohesion reached 2.43 kPa at 3%. These trends show that moderate fiber content (1–2%) is ideal for improving friction and compaction, while higher content (3%) is more effective for enhancing cohesion.
3. In conclusion, both sugarcane bagasse and corn husk fibers can effectively enhance the compaction and shear strength of sandy soil, supporting their use as eco-friendly soil reinforcement. However, it's important to choose the right fiber content which are 1–2% fiber content give better compaction and friction, and 3% for improved cohesion. Further studies should explore different soil types and examine the long-term durability of these natural fibers under environmental exposure.

Acknowledgement
The authors would like to thank Universiti Malaysia Sabah (UMS) for the full support given to this research work. This research was not funded by any grant.

References

[1] Wei, Jihong, Fanxuan Kong, Jin Liu, Zhihao Chen, Debi Kanungo, Xiaowei Lan, Canhui Jiang, and Xiao Shi. "Effect of Sisal Fiber and Polyurethane Admixture on the Strength and Mechanical Behavior of Sand." *Polymers* 10, no. 10 (October 10, 2018): 1121. https://doi.org/10.3390/polym10101121.

[2] Dang, Liet Chi, and Hadi Khabbaz. "Enhancing the Strength Characteristics of Expansive Soil Using Bagasse Fibre." In Proceedings of China-Europe Conference on Geotechnical Engineering Springer Series in Geomechanics and Geoengineering 1 (2018): 792–96. https://doi.org/10.1007/978-3-319-97112-4_177.

[3] Oderah, Vincent, and Denis Kalumba. "Laboratory Investigation of Sugarcane Bagasse as Soil Reinforcement Material." In Proceedings of the Fourth Geochina International Conference, July 21, 2016, 61–68. https://doi.org/10.1061/9780784480069.008.

[4] Roy, Priyanka, and Prasun Mukherjee. "Stabilization of Contaminated Soil by Mixing of Corn Husk Fibers." in Proceedings of the Indian Geotechnical Conference 2019: IGC-2019 Volume III, no. (pp. 701-716) (2021).

[5] Singh, Gurdeepak, and Sujata Sharma. "SOIL STABILIZATION USING CORN HUSK FIBER and STONE DUST." International Research Journal of Engineering and Technology, 2024.

[6] Moin, Sadia, and Sadaf Qasim. "Effect on Dynamic Parameters of Waste Reinforced Soil under Vibrations Generated through Traffic Loading: Experimental Evaluation." *Journal of Engineering Research* 13, no. 2 (December 28, 2023): 1650–57. https://doi.org/10.1016/j.jer.2023.12.011.

[7] Duong, Nga Thanh, Loc Xuan Luu, Tomoaki Satomi, and Hiroshi Takahashi. "Mechanical Property Enhancement of Cemented Soil Using Agricultural By-Product." Lecture Notes in Civil Engineering, December 11, 2023, 1159–66. https://doi.org/10.1007/978-981-99-7434-4_122.

[8] Aaqib Rasool Magray, and Preetpal Singh. "Improvement in the Properties of Soil by Utilization of Jute Fiber with Black Carbon as a Soil Reinforcement." Materials Today: Proceedings, April 1, 2023. https://doi.org/10.1016/j.matpr.2023.04.024.

[9] Aditi Sarker Ratna, Anik Ghosh, and Samrat Mukhopadhyay. "Advances and Prospects of Corn Husk as a Sustainable Material in Composites and Other Technical Applications." *Journal of Cleaner Production* 371 (2022): 133563. https://doi.org/10.1016/j.jclepro.2022.133563.

[10] Ali, M. M. "Identifying and Analyzing Problematic Soils." *Geotechnical and Geological Engineering* 29, no. 3 (November 3, 2010): 343–50. https://doi.org/10.1007/s10706-010-9380-y.

[11] Dang, Liet Chi, Behzad Fatahi, and Hadi Khabbaz. "Behaviour of Expansive Soils Stabilized with Hydrated Lime and Bagasse Fibres." *Procedia Engineering* 143 (2016): 658–65. https://doi.org/10.1016/j.proeng.2016.06.093.

[12] Duong, Nga Thanh, Tomoaki Satomi, and Hiroshi Takahashi. "Potential of Corn Husk Fiber for Reinforcing Cemented Soil with High Water Content." *Construction and Building Materials* 271 (February 2021): 121848. https://doi.org/10.1016/j.conbuildmat.2020.121848.

[13] Gowthaman, Sivakumar, Kazunori Nakashima, and Satoru Kawasaki. "A State-of-The-Art Review on Soil Reinforcement Technology Using Natural Plant Fiber Materials: Past Findings, Present Trends and Future Directions." *Materials* 11, no. 4 (April 4, 2018): 553. https://doi.org/10.3390/ma11040553.

[14] Hartemink, Alfred E, and Jingyi Huang. Sandy Soils. Progress in Soil Science. Springer International Publishing, 2023. https://doi.org/10.1007/978-3-031-50285-9.

[15] Hejazi, Sayyed Mahdi, Mohammad Sheikhzadeh, Sayyed Mahdi Abtahi, and Ali Zadhoush. "A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers." *Construction and Building Materials* 30 (May 2012): 100–116. https://doi.org/10.1016/j.conbuildmat.2011.11.045.

[16] Jodin Makinda, Heah Yee Ling, and Elsa Eka Putri. "Effects of Natural Fibre Reinforcement on the Shear Strength Properties of Soil." *Jurnal Bangunan, Konstruksi & Desain* 2, no. 1 (2024): 12–19. https://doi.org/10.25077/jbkd.2.1.12-19.2024.

[17] Liu, Can, Kui Lu, Zhiwen Wu, Xi Liu, Ankit Garg, Yinghong Qin, Guoxiong Mei, and Chao Lv. "Expansive Soil Improvement Using Industrial Bagasse and Low-Alkali Ecological Cement." *Construction & Building Materials* 423 (April 1, 2024): 135806–6. https://doi.org/10.1016/j.conbuildmat.2024.135806.

[18] Nga Thanh Duong, Khiem T Tran, Tomoaki Satomi, and Hiroshi Takahashi. "Effects of Agricultural By-Product on Mechanical Properties of Cemented Waste Soil" 365 (June 1, 2022): 132814–14. https://doi.org/10.1016/j.jclepro.2022.132814.