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Sustainable Stabilization of Clay Soil Using Starch and Coconut Coir Additives

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Abstract

Clay-rich soils are widely found in construction sites but pose engineering challenges due to their high plasticity, shrink-swell behavior, and poor strength under moisture variation. Although conventional stabilizers like cement and lime improve soil performance, they are environmentally harmful due to carbon emissions and high energy use. This research applies basic properties tests, including the Atterberg Limit test, moisture content, and dry sieve analysis test. This study aims to evaluate the strength behavior of the original and stabilized clay with added starch and coconut coir. To achieve this objective, proctor test was conducted on the original clay, as well as soil samples with 1% and 3% starch. The resulting Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) obtained from the compaction test were 23.4% and 1519 g/cm^3 respectively, and were used to prepare the samples for the unconfined compression test (UCT). The UCT results revealed that the stabilized clay samples exhibited higher strength than the original clay, with the unconfine compressive strength increasing from 76.6 kN/m^2 to 405.8kN/m^2 on day 21, demonstrating the effectiveness of starch and coconut coir as stabilizers. In conclusion, stabilizer starch with added coconut coir improved the strength and durability of the soil. Moreover, the soil sample with starch and coconut coir was found to exhibit better durability compared to the original soil sample.

1. Introduction

The rapid growth of the global population has led to an increasing demand for infrastructure development, which often necessitates construction on previously undeveloped land. In many regions, this expansion brings builders face-to-face with challenging geotechnical conditions, particularly the presence of clay-rich soils. Among these, expansive clay soils are considered some of the most problematic due to their tendency to undergo significant volumetric changes with fluctuations in moisture content. Typically, rich in minerals such as montmorillonite, these soils swell when they absorb water and shrink upon drying. This behavior results in structural issues such as differential settlement, cracking of foundations, pavement damage, and increased maintenance costs [1]. As a result, there is a critical need to improve the ground conditions in such areas to ensure the safety and longevity of civil engineering structures.

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One of the most established approaches to improving poor soil conditions is mass stabilization, a technique developed in Finland during the early 1990s and widely applied in large-scale infrastructure projects such as roads and railways. This method involves the in-situ mixing of binders commonly cement or lime into the soil to enhance its strength, reduce compressibility, and increase overall stability [2]. While traditional stabilizers like cement and lime are effective in modifying soil behavior, their production is associated with significant environmental concerns. The manufacture of cement, for instance, is energy-intensive and a major contributor to global greenhouse gas emissions [3]. As environmental awareness and regulatory pressures increase, the construction industry is under growing pressure to adopt more sustainable and environmentally responsible ground improvement techniques [4].

In response to these challenges, researchers have explored the potential of alternative materials that are both effective and sustainable. Among these alternatives are industrial by-products such as fly ash, blast furnace slag, rice husk ash, and silica fume, which offer a dual benefit: enhancing the geotechnical properties of expansive soils and promoting environmental conservation through waste recycling [4]. These materials help reduce the reliance on virgin resources, lower energy consumption, and support the principles of the circular economy. Additionally, the use of natural, biodegradable additives has attracted attention as a low-cost and eco-friendly method of soil stabilization. Natural fibers and biopolymers not only improve soil performance but also align with the global shift toward green construction practices.

In particular, the combined use of starch and coconut coir presents a promising solution for sustainable clay soil stabilization. Starch, a plant-based biopolymer derived from sources such as cassava and corn, acts as a binder that improves soil cohesion and reduces permeability [5]. Coconut coir, an agricultural byproduct widely available in tropical regions, offers excellent mechanical properties including tensile strength, flexibility, and durability. It has the potential to reduce the plasticity of clay soil, improve resistance to cracking, and enhance its structural integrity [6]. In addition to the enhancement of mechanical properties, understanding geotechnical parameters such as shear strength is crucial in assessing the soil's resistance to deformation and failure. This study thus evaluates the effect of natural additives on shear strength to ensure the long-term stability of treated soil layers.

Although some studies have used natural materials to improve soil, not many have combined cassava starch and coconut coir for expansive clay. Most previous research focused on each material separately. This project fills that gap by testing the combination of these two materials to assess their effects on soil, particularly strength, plasticity, and long-term performance. Previous studies by [7] showed that coconut coir can improve the compressive strength of soft clay, while another review by [8] highlighted its role in reducing erosion and increasing soil durability. However, none of these studies explored the joint effect of coconut coir with biopolymer binders like cassava starch. Therefore, this study offers a new approach by combining both materials to evaluate their interaction in soil stabilization.

Thus, in this study, the investigation on geotechnical behavior of combined materials coconut coir (cc) and starch (st) when added in expansive clay were connected. Through comprehensive laboratory testing including unconfined compressive strength, Atterberg limits, and durability assessments the research aims to evaluate the performance of these natural additives and determine their optimal proportions for practical application in sustainable construction.

2. Methodology

In this study, two additives were used which is cassava starch as the stabilizer and coconut coir as the filler and reinforcement. Cassava starch act as a natural binder due to its adhesive properties make it a natural glue that hold the soil particles together and improves the cohesion, reduces swelling, shrinking, and offers an eco-friendly alternative to chemical stabilizers. Coconut coir is a natural fiber extracted from coconut husks that acts as a reinforcement material in clay soil. Its high tensile strength and fibrous structure help improve the soil's mechanical properties by increasing its shear strength and reducing cracking. The coir fibers distribute stress more evenly and help resist deformation, especially during drying and wetting cycles. Being biodegradable and widely available, coconut coir is also an eco-friendly and cost-effective alternative to synthetic fibers. These materials were selected based on their performance in improving soil strength, reducing swelling potential, and achieving favorable compaction results in accordance with British standards.

2.1 Clay Sampling

A disturbed clay soil sample was collected from a farm in Kampung Sungai Buloh, Jelebu, Negeri Sembilan, Malaysia. Preliminary laboratory tests, including grain size distribution, Atterberg limits, and moisture content determination, were conducted to classify the soil and assess its basic geotechnical properties. For stabilization purposes, cassava starch was chosen as one of the additives due to its superior characteristics compared to other starches like corn or potato starch. Derived from the roots of the cassava plant, this biopolymer offers high starch yield, low impurity levels, excellent gelation, and adhesive properties that enhance the cohesion and

durability of soil-based materials. It is also widely available, cost-effective, and more suited for tropical regions, making it a sustainable alternative in construction. Additionally, coconut coir extracted from the outer husk of mature coconuts was used as a natural fiber additive. After harvesting, the coir was dried in the oven to remove moisture and then cut into 10 mm uniform pieces for use in soil stabilization. Known for its high tensile strength, moisture resistance, and biodegradability, coconut coir improves soil structure, reduces plasticity, and enhances long-term stability. Together, cassava starch and coconut coir were selected for their environmental benefits, mechanical performance, and potential to sustainably enhance the engineering behavior of clay soils.

2.2 Laboratory Test

The basic properties of the soil were first identified through the Atterberg limits test and the Dry Sieve Analysis test. The Atterberg limits Test included the determination of the liquid limit using the cone penetration method, as well as the plastic limit and plasticity index. The Dry Sieve Analysis was carried out to determine the particle size distribution and to remove oversized particles that could affect further testing.

The standard proctor compaction test was then conducted to determine the soil's optimum moisture content (OMC) and maximum dry density (MDD). Oven-dried soil was mixed with different amounts of water and compacted in three layers using a 2.5 kg rammer with 25 blows per layer. After compaction, the bulk density was calculated, and a sample was taken to determine moisture content. A graph of dry density versus moisture content was plotted to identify the OMC and MDD, which are important for achieving proper compaction in the field.

Lastly, the unconfined compressive strength (UCS) Test was performed to assess the shear strength of both untreated and stabilized soil samples. Cylindrical specimens were tested under axial load using a compression machine until failure or until 20% axial strain was reached. The peak stress before failure was recorded as the UCS value, and moisture content tests were conducted on the specimens after testing for further analysis.

3. Result & Discussion

The primary objective was to evaluate the performance and effectiveness of these natural additives in improving the geotechnical properties of clay soil. Key parameters investigated include soil strength, moisture content, and unconfined compressive strength (UCS).

3.1 Basic Properties

Basic properties tests such as the moisture content test, plastic limit test, liquid limit test, and dry sieve analysis were used to classify the type of soil. Based on the results obtained in Table 1, the value of the plasticity index is 19.24%. According to the Unified Soil Classification System (USCS), the soil is classified as clay with high plasticity.

Table 1 *Basic properties of clay*

Properties	Value
Moisture content (%)	30.43
Plastic Limit (%)	37.35
Liquid Limit (%)	56.58
Plasticity Index (%)	19.24

3.1.1 Dry Sieve Analysis

A soil sample is run through a stack of sieves with progressively smaller mesh opening sizes in this experiment, and the weight retained on each sieve is measured to determine the grain size distribution curve. The soil fraction bigger than 75 meters is often subjected to sieve analysis. The analysis was conducted using the standard set of sieves, and the percentage of soil retained on each sieve was calculated. In Fig. 1, the data have been analyzed and put together in a graph to get the particle size distribution curve. These results provide essential information regarding the gradation and texture of the soil.

Fig. 1 illustrates the particle size distribution curve obtained from dry sieve analysis. The soil sample consists of a wide range of particle sizes, with D60, D30, and D10 values recorded as 5.8 mm, 2.1 mm, and 0.77 mm respectively. These values represent the particle diameters at which 60%, 30%, and 10% of the soil mass is finer, and are used to calculate the Uniformity Coefficient (Cu) and Coefficient of Curvature (Cc). Using the standard formulas, the Cu value is calculated as 7.53 and the Cc as 0.98. According to soil classification guidelines, a Cu value greater than 6 with a Cc value between 1 and 3 usually indicates well-graded sand. However, the Cc here is slightly below the ideal range, suggesting the soil is poorly graded. This means the

particles do not vary widely in size and have limited interlocking potential. As a result, the soil may have low compaction ability and reduced stability when used alone, which reinforces the need for treatment using cassava starch and coconut coir to enhance its structural properties.

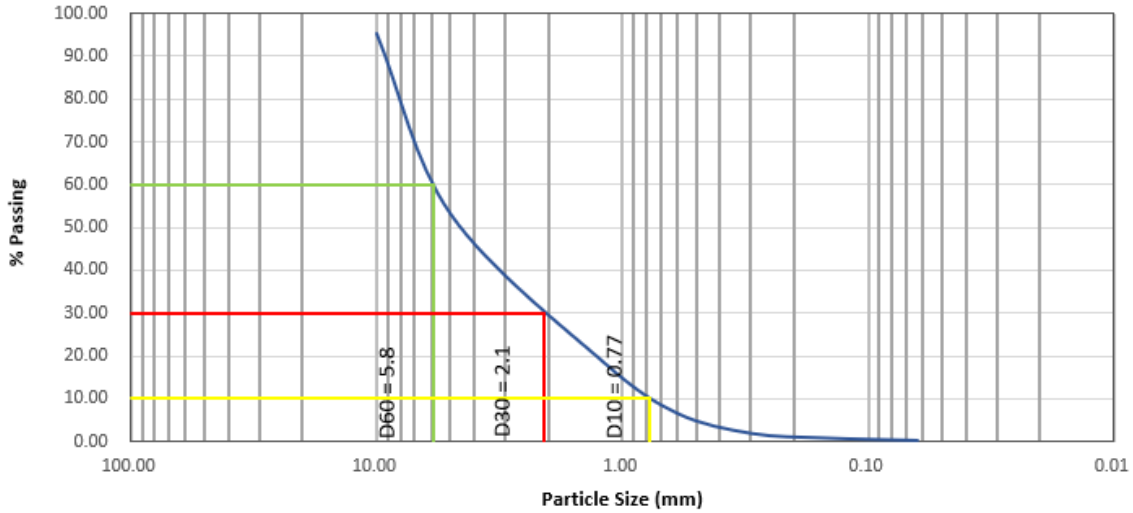

Fig. 1 *Dry sieve analysis data for clay*

3.2 Proctor Test

The connection between the clay soil's dry density and moisture content was determined using the Proctor Compaction Test. Compaction is a process that increases the dry density of soil by packing solid particles closer together, generally by mechanical means [9]. The amount of water in the soil and the level of compaction used determine the dry density that may be achieved [10]. There is an ideal moisture content at which the dry density achieved for a particular cohesive soil reaches its maximum value for a given degree of compaction. It may be challenging to determine the ideal moisture content for cohesionless soils. Finding the maximum dry density (MDD) and optimal moisture content (OMC) of the soil and the soil with the stabilizer is the aim of this test. The maximum dry density (MDD) and optimal moisture content (OMC) for each clay soil and starch mixture are shown in Fig. 2 where the result shown that the mixture of soil and starch stabilizer of 3% starch shows the highest maximum dry density (MDD) and the lowest optimal moisture content (OMC). The 3% starch mix achieved the highest maximum dry density due to optimal soil-starch interaction. At this dosage, the starch effectively filled soil voids and enhanced inter-particle bonding, leading to better compaction. Higher starch contents likely reduced efficiency by disrupting particle arrangement or introducing more voids.

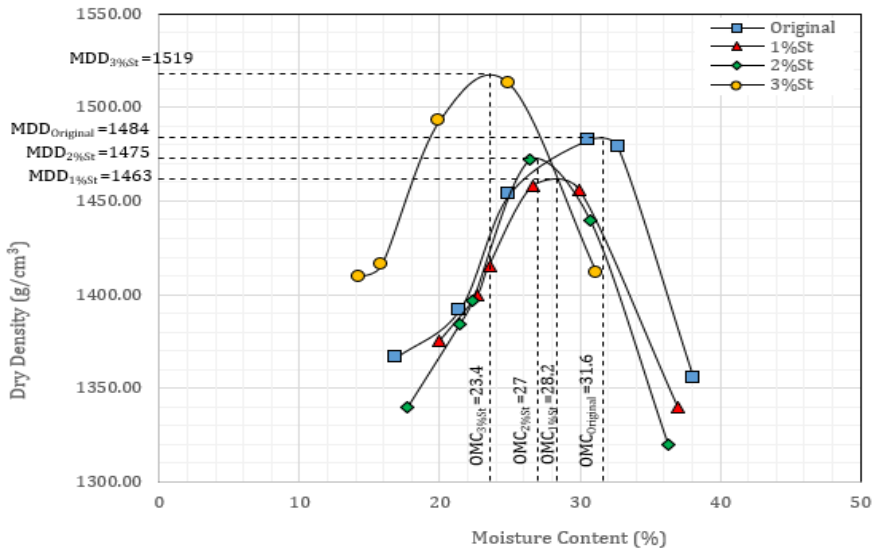

Fig. 2 *Data of proctor test*

3.3 Unconfined Compresstion Test

Fig. 3 and Fig. 4 present the stress-strain curves of six different soil samples that were treated with various combinations of cassava starch and coconut coir, and cured for 14 and 21 days respectively. These graphs illustrate how curing time and stabilizer composition influenced the compressive behavior of the clay, showing differences in stiffness, peak strength, and failure strain between treated and untreated samples under unconfined loading conditions.

Table 2 summarizes the stress and strain value of the sample. For the 14-day curing, the sample of original clay recorded the lowest UCS value of 50.3 kN/m^2, highlights weak soil structure without stabilizer. The strength improved progressively with the addition of 3% starch achieving 267.1kN/m^2. Sample with added 3% and coconut coir showed even higher strength reaching 341.9kN/m^2, reveals that the combination of starch and coconut coir improves bonding and internal friction between particles.

After 21-day curing, sample with added 3% starch and coconut coir showing highest strength, 405.8 kN/m^2. The continuous chemical and physical interactions between the additives and the clay matrix over time were responsible for the improvement.

Fig. 5 displays the visual failure mode on the clay sample after UCS testing. Sample (a), which was stabilized with starch and coconut coir, reveals a brittle failure meanwhile sample (b) failed by slowly bulging outward indicative of ductile failure.

Overall, the results confirm that the addition of starch and coconut coir significantly increase the compressive strength of clay soil. The increases in UCS with longer curing time also support the hypothesis that the natural stabilizers require time to bond and react within the soil structure. Among all, sample 3% starch with coconut coir showed the highest performance.

Table 2 *Stress and strain value*

Curing Time	Day 14		Day 21	
Sample	Stress (kN/m^2)	Strain (%)	Stress (kN/m^2)	Strain (%)
Original	50.3	23	76.6	25
Original + Starch1%	90.8	23.7	95.4	21.1
Original + Starch3%	267.1	7.9	298	8.6
Original + CC	77.6	26	88.9	26.3
Original + Starch1% + CC	146.8	19.1	205.5	15.1
Original + Starch3% + CC	341.9	11.8	405.8	9.2

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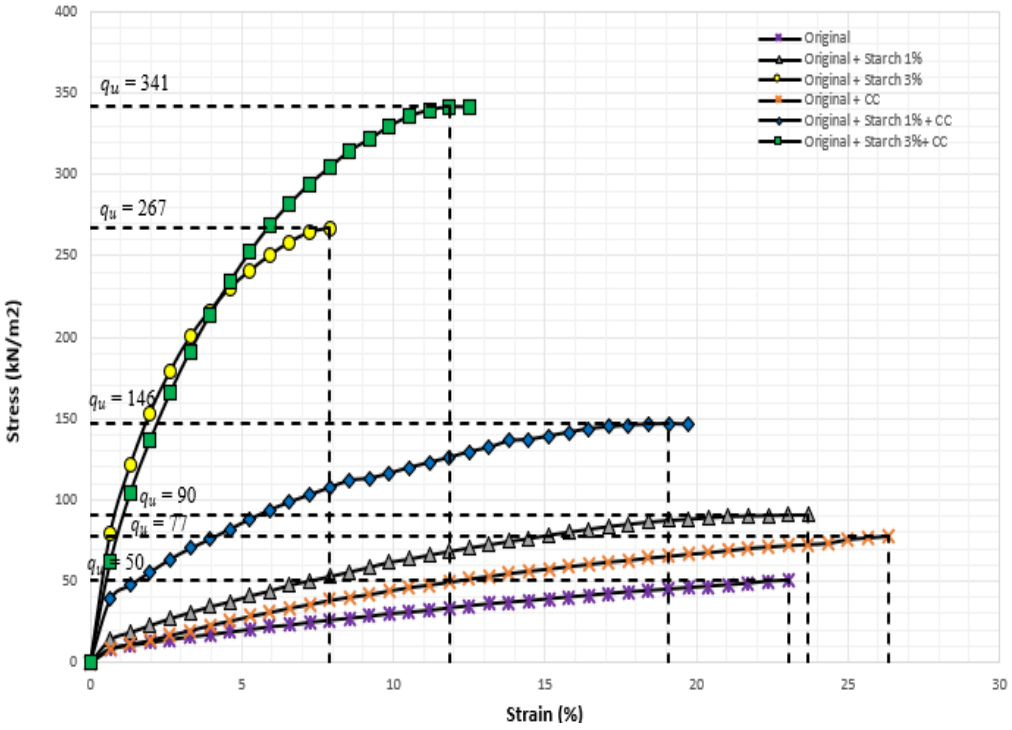

Fig. 3 *Unconfined compression test for 14 days curing*

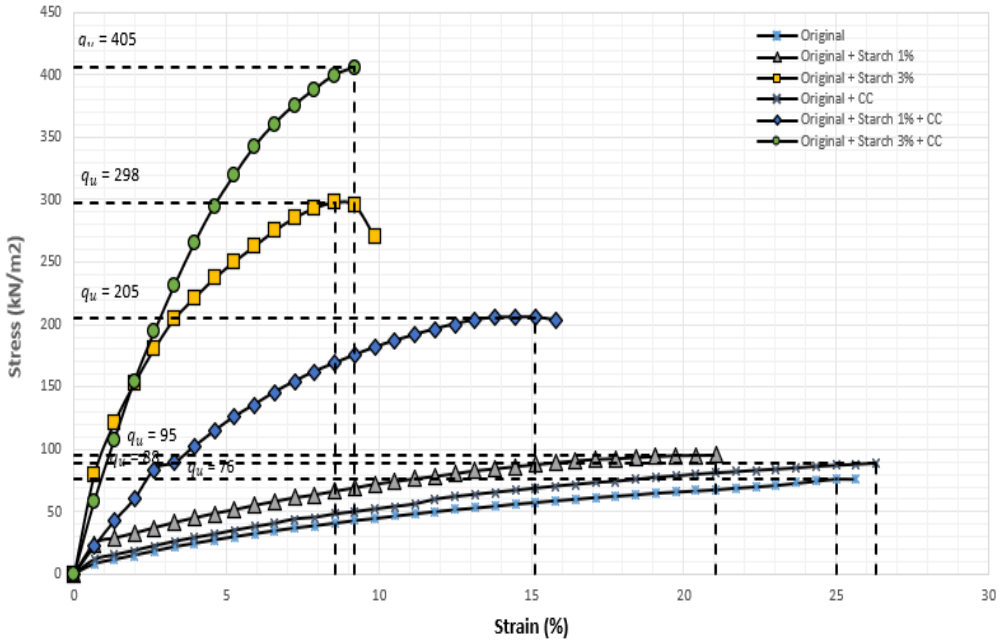

Fig. 4 *Unconfined compression test for 21 days curing*



(a) (b)

Fig. 5 *Sample condition after UCT for (a) clay with stach and coconut coir; (b) original*

4. Conclusion

In conclusion, this study aims to identify the effectiveness of coconut fiber and starch as natural stabilizers for clay, by evaluate the strength behavior of the original and stabilized clay with added starch and coconut coir. Based on the Unconfined Compression test, the result indicated that all treated samples showed improvement in strength compared to original clay soil. However, the sample stabilized with 3% starch and 1 cm coconut coir achieved the highest strength performance, with 144.83% increase in UCS value. Therefore, the objective of this study to evaluate the strength behavior of the original and stabilized clay was successfully achieved. The findings support the potential use of starch and coconut coir as eco-friendly and sustainable alternatives to traditional chemical stabilizers in geotechnical engineering.

5. Recommendation

The long-term durability and environmental effects of using starch and coconut coir as stabilizers in field settings, such as wetting-drying and freeze-thaw cycles, should be investigated in future studies. To compare performance and cost-effectiveness, tests may also be conducted using varying percentages or types of natural fibers, such as rice husk and bamboo fiber. Further promotion of the use of locally produced organic stabilizers is necessary as a sustainable and eco-friendly substitute for conventional chemical additives like lime and cement.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Siti Nooraiin Mohd Razali, Norsyakirin Hamidan, Muhammad Nifael Mohd Hairi, Muhamad Faizzul Hafif Jalil;* ***data collection:*** *Norsyakirin Hamidan, Muhammad Nifael Mohd Hairi, Muhamad Faizzul Hafif Jalil;* ***analysis and interpretation of results:*** *Siti Nooraiin Mohd Razali, Norsyakirin Hamidan, Muhammad Nifael Mohd Hairi, Muhamad Faizzul Hafif Jalil;* ***draft manuscript preparation:*** *Norsyakirin Hamidan, Muhammad Nifael Mohd Hairi, Muhamad Faizzul Hafif Jalil. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] O. Buzzi, S. Fityus, and S. W. Sloan, "Use of expanding polyurethane resin to remediate expansive soil foundation," Canadian Geotechnical Journal, May 2010.

[2] R. B. Saldanha, V. F. Nuñez, A. Lotero, and N. C. Consoli, "*Life cycle assessment of green binder for organic soil stabilization*," Transportation Geotechnics, vol. 49, Art. no. 101398, 2024.

[3] I. T. Jawad, M. R. Taha, Z. H. Majeed, and T. A. Khan, "*Soil stabilization using lime: Advantages, disadvantages and proposing a potential alternative*," Research Journal of Applied Sciences, Engineering and Technology, vol. 8, no. 4, pp. 510–520, 2014.
[4] S. Almuaythir, M. S. I. Zaini, M. Hasan, and M. I. Hoque, "*Sustainable soil stabilization using industrial waste ash: Enhancing expansive clay properties*," Heliyon, vol. 10, no. 20, 2024.
[5] M. G. L. Ramírez, K. G. Satyanarayana, S. Iwakiri, G. B. de Muniz, V. Tanobe, and T. S. Flores-Sahagun, "*Study of the properties of biocomposites. Part I. Cassava starch-green coir fibers from Brazil*," Carbohydrate Polymers, vol. 86, no. 4, pp. 1712–1722, 2011.
[6] W. Nansu, S. Ross, G. Ross, and S. Mahasaranon, "*Effect of crosslinking agent on the physical and mechanical properties of a composite foam based on cassava starch and coconut residue fiber*," Materials Today: Proceedings, vol. 17, pp. 2010–2019, 2019.
[7] N. M. N. A. Nik Hasan, "*Soft soil stabilization using coconut coir agriculture waste*," Bachelor's degree project, Faculty of Civil Engineering, Universiti Teknologi MARA, Pulau Pinang, Malaysia, Jan. 2019. [Online]. Available: https://ir.uitm.edu.my/id/eprint/39640/
[8] Vibhu, M. K. Rana, and P. Kushwaha, "*Review paper on 'Studies on soil stabilization by using coconut coir'*," International Journal of Research and Analytical Reviews (IJRAR), vol. 10, no. 3, pp. 742–749, Aug. 2023.
[9] Methods of Test for Soils for Civil Engineering Purposes—Part 4: Compaction-Related Tests, BS 1377-4, 1990.
[10] Methods of Test for Soils for Civil Engineering Purposes—Part 7: Shear Strength Tests (Total Stress), BS 1377-7, 1990.