

A REVIEW OF THE DIFFERENT TYPES OF SOIL STABILIZATION TECHNIQUES - TREATMENT WITH AGRICULTURAL WASTE UNE REVUE DES DIFFÉRENTES TECHNIQUES DE STABILISATION DES SOLS - TRAITEMENT AVEC DES DÉCHETS AGRICOLES

Réception : 05/11/2024

Acceptation : 30/12/2024

Publication : 10/01/2025

OUMRICH Kamel¹, DJOUIMAA Sara², HANDEL Naoual³, NADOUR Fethi⁴, HOUHAMDI Azzedin⁵

^{1,2,3,4,5}Laboratoire de Gestion, Maintenance et Réhabilitation des Equipements et des Infrastructures Urbaines - Université de Souk-Ahras.

¹k.oumrigh@univ-soukahras.dz

²s.djouimaa@univ-soukahras.dz

³n.handel@univ-soukahras.dz

⁴f.nadour@univ-soukahras.dz

⁵az.houhamdi@univ-soukahras.dz

Résumé - La stabilisation des sols est un processus vital pour améliorer les paramètres de résistance au cisaillement des sols et augmenter leur capacité portante, en particulier lorsque le sol existant est insuffisant pour supporter des charges structurales. Cela implique souvent de corriger les propriétés d'ingénierie indésirables des sols par des modifications visant à améliorer leurs propriétés physiques. En augmentant la résistance au cisaillement et en gérant les caractéristiques de retrait et de gonflement, la stabilisation vise à renforcer la capacité portante des sols pour soutenir les pavés et les fondations. Cela implique un examen de l'effet de la stabilisation sur les sols, y compris les mécanismes d'interaction avec les additifs, l'impact sur la résistance et l'amélioration de la teneur en humidité et de l'entretien. La stabilisation mécanique se concentre sur l'amélioration des propriétés du sol en modifiant leur gradation, tandis que la stabilisation chimique consiste à modifier les conditions physiques et chimiques entourant les particules d'argile pour réduire l'absorption d'eau et le mouvement au sein de la matrice du sol. Ces méthodes sont cruciales pour diminuer la perméabilité et la compressibilité dans les structures souterraines tout en améliorant la résistance au cisaillement. L'utilisation de déchets agricoles pour améliorer les propriétés des sols est significative. L'industrie agricole produit de grandes quantités de déchets, ce qui contribue à des problèmes environnementaux tels que la pollution de l'eau et de l'air. Des exemples notables incluent les cendres de coque de riz et les cendres de canne à sucre produites par les moulins. Les cendres de coque de riz, riches en silice amorphe, servent de stabilisateur efficace, tandis que les cendres de canne à sucre sont riches en silice et en oxydes d'aluminium. Cet article examine la stabilisation des sols expansés à l'aide de résidus agricoles dans des proportions variées (5 %, 10 %, 15 %, 20 %) et détermine la Masse Sèche Maximale (MSM) par le biais du test de Proctor standard. Divers tests, y compris le test de Résistance Compressive Non Confinée (RCNC) à des intervalles de durcissement de 7, 14 et 28 jours, ainsi que le test du Rapport de Portance de Californie (RPC), ont été effectués. Les résultats révèlent une augmentation de la résistance au cisaillement et une diminution de la compressibilité des sols. Dans l'ensemble, comprendre les différents aspects des techniques de stabilisation des sols est essentiel pour assurer le succès des projets de construction en abordant efficacement les propriétés des sols qui impactent la stabilité et la capacité portante.

Mots - clés : Stabilisation des sols, Sols expansifs, Déchets agricoles, CBR, Résistance à la compression non confinée.

Abstract-Soil stabilization is a vital process for enhancing the shear strength parameters of soils and increasing their bearing capacity, particularly when the existing soil is inadequate for supporting structural loads. This often entails correcting undesirable engineering properties of soils through modifications aimed at improving their physical properties. By increasing shear strength and managing shrinkage and swelling characteristics, stabilization seeks to boost the bearing capacity of soils for supporting pavements and foundations. It involves an examination of how stabilization affects soils, including the mechanisms of interaction with additives, the impact on strength, and the

enhancement of moisture content and maintenance. Mechanical stabilization concentrates on improving soil properties by altering their gradation, while chemical stabilization entails modifying the physical and chemical conditions surrounding clay particles to reduce water absorption and movement within the soil matrix. These methods are crucial in decreasing permeability and compressibility in ground structures while enhancing shear strength. The use of agricultural waste to improve soil properties is significant. The agricultural industry produces large quantities of waste, which contributes to environmental issues such as water and air pollution. Notable examples include rice husk ash and sugarcane ash generated by mills. Rice husk ash, rich in amorphous silica, serves as an effective stabilizer, while sugarcane ash is high in silica and aluminum oxides. This paper reviews the stabilization of expanded soil using agricultural residues in varying proportions (5%, 10%, 15%, 20%) and determines the Maximum Dry Density (MDD) through the standard Proctor test. Various tests, including the Unconfined Compressive Strength (UCS) test at curing intervals of 7, 14, and 28 days, as well as the California Bearing Ratio (CBR) test, were conducted. The findings reveal an increase in shear strength and a decrease in soil compressibility. Overall, understanding the different aspects of soil stabilization techniques is essential for ensuring the success of construction projects by effectively addressing soil properties that impact stability and load-bearing capacity.

Keywords: Soil stabilization, Expansive soil, Agricultural wastes, CBR, unconfined compressive strength,

1-Introduction

Expanded soil exhibits swelling properties. Agricultural waste presents a significant challenge in developing countries, but these wastes can serve as effective stabilizing agents. Clay soil poses construction difficulties for infrastructure, such as pavements and foundations. During the rainy season, expanded soil absorbs water, swells, and becomes soft, while in dry conditions, it shrinks and solidifies as moisture evaporates. To enhance clay soil characteristics, agricultural waste materials are utilized. Research shows that Sugarcane Residue Ash (SCBA) offers a cost-effective stabilization solution, while Rice Husk Ash (RHA) effectively binds soil particles, reducing water absorption and increasing soil durability and strength. Agricultural wastes are mainly of four types as shown in Figure 1. They consist of crop, food, industrial processing and livestock wastes. They are generated after the extraction of the useful part of the crop or during livestock rearing. Like any other waste, agricultural wastes need to be managed properly for a healthy environment through various waste management strategies. These strategies include utilizing agricultural wastes to produce new products as value addition to the agricultural economy. These agricultural wastes are incinerated to produce agricultural waste ash. Some of the new products that can be produced from agricultural waste ash are SNPs. SNPs are produced either through bottom-up or top-down

methods using non-renewable minerals such as silica sand. There is a need to reduce the use of non-renewable resources to produce SNPs. This has led to research on the use of AWAs to produce SNPs that are considered green. This leads to the management of AWs while enhancing value addition in agriculture. These SNPs can be used as pozzolanic additives in civil engineering projects to strengthen concrete, and produce plastic and rubber materials. This leads to sustainable construction. In this review, recent advances in soil stabilization, bitumen and asphalt in the road construction sector are studied.

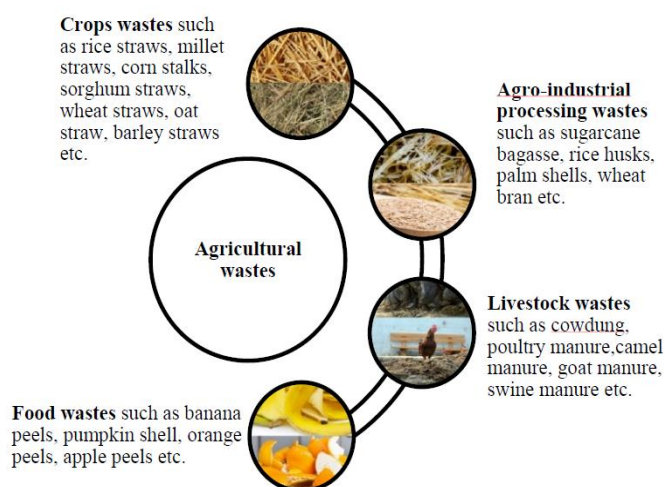


Figure 1: Types of agricultural wastes.

Table 1: Agricultural wastes ashes containing silica as characterised by x-ray fluorescence spectroscopy (XRF) from different studies

Biomass ash	Silica (SiO ₂) (%)	Reference
Rice husk ash	72.2–99.50	[1]–[6]
Areca sheath ash	78.00	[7]
Sugar cane bagasse ash	40.46–98.40	[8]–[16]
Palm leaf ash	53.11–82.15	[17], [18]
Corn cob ash	64.80	[19]
Barley straw ash	55.00–61.75	[20], [21]
Bamboo leaf ash	72.81	[22]
Millet husk ash	69.40	[23]
Wheat straw ash	67.83	[23]
Wood ash	7.75–68.51	[24]–[27]
Sorghum huskash	70.48	[28]
Paddy waste ash	84.78	[29]
Ficus leaf ash	81.45	[30]
Palm oil fuel ash	61.68	[31]
Sunflower ash	50.36	[32]
Anacardium ash	65.02	[33]
Cowdung ash	57.33–61.00	[34], [35]

2- Soil Stabilization Methods

2.1- Husk Ash as a Soil Stabilizer in Road Construction

The use of coconut husk ash (CHA) as a low-cost alternative to traditional soil stabilizers, such as cement and lime, in road construction projects is particularly significant in developing countries where local soils lack the required engineering properties. Laboratory experiments were conducted on mixtures of clay soil and coconut husk ash in proportions ranging from 0% to 20% to determine its effect on the physical and mechanical properties of the soil.

2.1.1- Chemical Composition: Coconut husk ash consists of oxides such as SiO₂, K₂O, and CaO, making it a suitable pozzolanic material.

2.1.2- Mix Properties: The results showed that the optimal CHA content for improving soil strength was at 8%, where California Bearing Ratio (CBR) values and Unconfined Compressive Strength (UCS) increased with the ash content up to this percentage, after which the values began to decline with higher ratios.

2.1.3- Applications: Despite the improvements achieved with the mixtures, the use of coconut husk ash alone is insufficient for stabilizing soil in major foundations. It is recommended to combine it with traditional stabilizers to

enhance performance in base layers and sub-layers.

2.2- The Effect of a Mixture of Sorghum Straw Ash and Lime on Clayey Soil:

The impact of a mixture of sorghum straw ash (GCHA) and lime on improving the properties of clayey soil used in the construction of highways is significant, especially since this type of soil often faces stability issues due to environmental factors and excessive loading.

2.2.1- Improvement Tests: The results indicated that the addition of GCHA and lime in proportions of 2%, 3%, and 4% for GCHA and 4%, 6%, and 8% for lime significantly enhanced the soil properties:

Maximum Dry Density (MDD): Increased from 1.71 mg/cm³ to 1.86 mg/cm³.

California Bearing Ratio (CBR): Rose from 3% to 12% at 3% GCHA and 6% lime.

Unconfined Compressive Strength (UCS): Increased from 157.35 kN/m² to 357.14 kN/m² at the same proportions.

2.3- Rice Husk Ash and Coconut Husk Ash:

The use of agricultural wastes such as Rice Husk Ash (RHA) and Coconut Husk Ash (CS) to enhance the properties of clayey soil utilized in the subbase layer of roads is gaining attention. Untreated clayey soil is typically weak in strength, necessitating improvement through the incorporation of additional materials.

2.3.1- Results: Geotechnical Properties: The findings indicated an increase in optimal moisture content (OMC) and a slight decrease in maximum dry density (MDD) with the addition of RHA and CS

Unsoaked Condition: CBR values significantly increased with the addition of CS and RHA, reaching 36.75% at the top layer and 40.81% at the bottom layer when using 8% CS and 20% RHA.

Soaked Condition: The results demonstrated an increase in CBR values compared to untreated soil, indicating a substantial improvement in strength.

2.4- Evaluation of Cassava Peels Ash (CPA) and Cement Performance:

The effect of adding Cassava Peels Ash (CPA) on the engineering properties of soil aims to enhance the properties of the soil by utilizing CPA and cement, contributing to agricultural waste management and reducing reliance on traditional cement. CPA was added in proportions of 0%, 2%, 4%, 6%, 8%, and 10%, with the addition of 5% cement in some samples.

2.4.1- Results:

Atterberg Limits: There was an increase in the liquid limit with an increase in CPA content, while the plastic limit decreased. Maximum Dry Density (MDD) This decreased with an increase in CPA.

California Bearing Ratio (CBR): Increased from 15% for natural soil to 22% at 8% CPA, and rose further with the addition of cement.

Unconfined Compressive Strength (UCS): Increased from 21.09 kN/m² to 32.80 kN/m² at 10% CPA

These results underscore the potential of utilizing rice husk ash and coconut husk ash as effective materials for enhancing the geotechnical properties of clayey soils, thereby contributing to improved performance in road construction.

2.5- The effect of mango straw ash (MSA) :

The effect of mango straw ash (MSA) on black cotton soil, which is considered expansive and unsuitable for construction purposes. The objective of the study is to assess the suitability of MSA for improving soil properties for use in road construction.

2.5.1- Results:

Improvement of geotechnical properties:

California Bearing Ratio (CBR): Increased by 85.7% with the addition of 15% MSA. **Unconfined Compressive Strength (UCS):** Improved by 60.24% with the optimal value at 15% MSA.

Maximum Dry Density (MDD): Increased by 60%.

Optimum Moisture Content: Decreased by 54%. **Free Swell Index:** Decreased by 33.33%. **Specific Gravity:** Increased by 62.5%. **Plastic Limit:** Decreased by 62.6%. **Plasticity Index:** Decreased by 61.34%.

2.6- Assessment of the Impact of Using Palm Fiber Ash :

Using natural components such as palm fiber ash is considered a sustainable option for improving the performance of materials used in infrastructure projects, especially in countries where these materials are abundant.

2.6.1- Dry Density and Mechanical Properties:

It was found that the increase in the content of palm fiber ash leads to a slight decrease in maximum dry density, while the optimum moisture content improved. A significant improvement in the California Bearing Ratio (CBR) was observed, with the highest value reaching 190.09% after soaking when using a mix containing 80% laterite soil, 14% palm fiber ash, and 6% cement.

2.6.2- Improvement of Engineering Performance:

Experiments showed that the soil treated with palm fiber ash and cement exhibited better unconfined compressive strength, making it more resistant to loads and repeated stresses, thus enhancing the stability of roads when used in high traffic environments..

2.7- Effect of Using Ground Palm Kernel Shells (PPKS)

Tests were conducted to determine the engineering properties of this soil after adding varying percentages of PPKS ranging from 5% to 12.5%.

2.7.1- Physical Properties:

The laterite soil exhibited a liquid limit of 36% and a plastic limit of 26.18%, indicating a reduced susceptibility of the soil to shrinkage or cracking.

The maximum dry density (MDD) increased from 1.76 to 1.94 kg/m³ with the increasing content of PPKS.

Optimum Moisture Content (OMC): The optimum moisture content decreased from 14.69% to 12.65% with the increase in PPKS percentage, indicating an improvement in the engineering properties of the soil.

California Bearing Ratio (CBR): The wet CBR value increased from 24% to 53% with the addition of 12.5% PPKS, indicating a significant improvement in the strength of the soil as a construction material for roads.

Unconfined Compressive Strength (UCS): The unconfined compressive strength increased from 46.69 to 127.08 kg/m² with the increase in PPKS content, reflecting a substantial improvement in soil strength

2.8- Effect of Adding Egg Shell Ash (ESA) on Improving Soil Properties

2.8.1- Chemical Analysis of Egg Shell Ash

Eggshell ash contains a high percentage of calcium oxide (CaO) reaching 68.20%, while the silica (SiO₂) content is low at 11.29%.

California Bearing Ratio (CBR) Test: The results showed an increase in CBR values (both saturated and unsaturated) with the increasing content of ESA, with peak values achieved at 8% ESA. For example, in Ekiti State, the saturated CBR value rose from 31.85% (0% ESA) to 36.44% (8% ESA).

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Tests: MDD increased with the rise in ESA content, while OMC decreased. The highest MDD was achieved at 8% ESA.

Unconfined Compressive Strength (UCS) Test: The UCS results showed a significant increase in strength with the increasing ESA content, with values ranging from 464.10 to 1032.20 kN/m², achieving peak values at 8% ESA.

Direct Shear Test: The results of the direct shear test indicated an increase in cohesion (C) and internal friction angle (ϕ) values with the rise in ESA content, with peak values reached at 8% ESA.

2.9- Soil Stabilization Using Groundnut Straw Ash (GSA)

Using groundnut straw ash (GSA) as a stabilizing agent for expansive clay soil comes at a time of rising costs for traditional stabilizing agents and the need to utilize agricultural and industrial waste economically.

2.9.1- Stabilization Results:

The highest unconfined compressive strength (UCS) of 455 kN/m² was achieved with the addition of 4% GSA using the standard Proctor compaction method, and 526 kN/m² was achieved with 6% GSA using the West African compaction method.

The results did not meet the recommended requirements for base materials, as they were below 1710 kN/m².

The California Bearing Ratio (CBR) test results indicated that the values did not reach the minimum required threshold for base or sub-base materials.

2.10- Using Bagasse Ash for Stabilizing Expansive Soil

This study addresses the use of bagasse ash as a stabilizing material for expansive soils, which pose challenges in civil engineering due to their properties of swelling and shrinkage when exposed to water. The aim of the study is to improve the characteristics of this soil using bagasse ash as an economical and sustainable alternative.

2.10.1- Study Results

Improvement of Properties: The results showed that the addition of 6% bagasse ash led to a significant improvement in the soil's engineering properties, with an increase in maximum dry density by 5.8%, an increase in California Bearing Ratio (CBR) by 41.52%, and an increase in unconfined compressive strength by 43.58%.

Effect of Ratios: The best results were observed when 6% of the soil was replaced with bagasse ash, while the properties decreased with higher ratios of 9% and 12%.

2.10.2- Chemical Properties of Bagasse

Ash: Bagasse ash contains a high silica content, which imparts pozzolanic properties that help improve the cohesion of the soil.

3-Recommendations

Future research needs to focus on:

Evaluating the operational characteristics of these components over time.

Conducting field studies to analyze the actual performance of the treated roads.

Considering the economic and environmental quality of generalizing this method in infrastructure projects.

These findings underscore the importance of using sustainable techniques in road construction, positively impacting sustainable development and environmental conservation.

Further research is recommended to explore other properties and their effects on different soil types, which could contribute to improving the sustainability of construction projects and reducing agricultural waste.

This research highlights the significance of using sustainable agricultural materials to enhance soil properties, contributing to the development of more sustainable infrastructure.

3- Conclusion

The study represents an important step towards exploring sustainable and environmentally friendly alternatives to traditional soil stabilizers, enhancing the potential for using local resources in infrastructure projects.

The use of CS (Calcium Sulfate) and RHA (Rice Husk Ash) significantly improves the engineering properties of clay soils, making them more suitable for use in road base layers.

This research is a significant step towards utilizing natural materials as sustainable alternatives in construction projects, which reduces costs and lessens environmental impact.

The study demonstrated that using CPA (Calcium Phosphate Ash) as a stabilizing agent can improve the engineering properties of soils, making them suitable for road construction.

The soil's classification changed from A-7-5 to A-2-7 with the addition of 10% CPA, indicating a notable improvement in quality.

The results indicate that mango straw ash (MSA) has the potential to enhance the engineering properties of black cotton soil, making it suitable as a paving material for roads.

The study confirms that introducing palm fiber ash as a sustainable method for soil improvement can enhance its applications in construction, as it is an environmentally friendly and cost-effective option, while also reducing waste from palm processing.

Further research is recommended to explore the behavior of these materials under varying conditions, such as dynamic loads and changing climates, to gain a deeper understanding of their performance in practical applications..

Sugarcane straw ash can be used as an effective alternative to improve the properties of black cotton soil up to a ratio of 6% without the need for additional chemical or cementitious materials.

The results indicate that the use of sugarcane straw ash could be an economical and environmentally friendly solution to soil stabilization issues, contributing to the reduction of agricultural waste.

Effective stabilization of black cotton soil could not be achieved using peanut straw ash as a stabilizing agent.

Nevertheless, the ash showed the ability to improve strength over time, suggesting its potential for use in other applications or in combination with additional materials to enhance its effectiveness.

Références bibliographiques

- [1] Abbass, M. & Singh, G., Impact strength of rice husk ash and basalt fibre based sustainable geopolymer concrete in rigid pavements. *Materials Today: Proceedings*, 2021.
- [2] Bixapathi, G. & Saravanan, M., Strength and durability of concrete using rice husk ashes a partial replacement of cement. *Materials Today: Proceedings*, 2021. Pour chaque auteur, on écrit son nom avec une majuscule pour la première lettre suivie d'une virgule, suivi de l'initiale en majuscule du prénom suivie d'un point.
- [3] da Silva Nuernberg, N.B., Niero, D.F. & Bernardin, A.M., Valorization of rice husk ash and aluminum anodizing sludge as precursors for the synthesis of geopolymers. *Journal of Cleaner Production*, **298**, 126770, 2021.
- [4] Jittin, V. & Bahurudeen, A., Evaluation of rheological and durability characteristics of sugarcane bagasse ash and rice husk ash based binary and ternary cementitious system. *Construction and Building Materials*, **317**, 125965, 2022.
- [5] Mahdi, S.N., Babu, R.D.v., Hossiney, N. & Abdullah, M.M.A.B., Strength and durability properties of geopolymer paver blocks made with fly ash and brick kiln rice husk ash. *Case Studies in Construction Materials*, **16**, e00800, 2022.
- [6] Wang, J., Fu, J., Song, W. & Zhang, Y., Effect of rice husk ash (RHA) dosage on pore structural and mechanical properties of cemented paste backfill. *Journal of Materials Research and Technology*, **17**, pp. 840–851, 2022.
- [7] Kulkarni, P.P. & Siddeswarappa, B., A study on microstructure and mechanical behaviour of AA6063 metal matrix composite reinforced with areca sheath ash (ASA) and rice husk ash (RHA). *Materials Today: Proceedings*, 2021.
- [8] Dang, L.C., Khabbaz, H. & Ni, B.J., Improving engineering characteristics of expansive soils using industry waste as a sustainable application for reuse of bagasse ash. *Transportation Geotechnics*, **31**, 100637, 2021.
- [9] Dinesh Kumar, P.K., Rajendran, B., Subeetsha, B. & Swetha, N., Study on tensile, flexural and impact strength of GLARE reinforced with sugarcane bagasse ash microparticles. *Materials Today: Proceedings*, **47**, pp. 1059–1064, 2021.
- [10] de Siqueira, A.A. & Cordeiro, G.C., Properties of binary and ternary mixes of cement, sugarcane bagasse ash and limestone. *Construction and Building Materials*, **317**, 126150, 2022.
- [11] Nurwahid, I.H., Dimonti, L.C.C., Dwiatmoko, A.A., Ha, J.M. & Yunarti, R.T., Investigation on SiO₂ derived from sugarcane bagasse ash and pumice stone as a catalyst support for silver metal in the 4-nitrophenol reduction reaction. *Inorganic Chemistry Communications*, **135**, 109098, 2022.
- [12] Salhotra, S., Khitoliya, R.K. & Kumar Arora, S., Assessing the enhanced concrete properties induced by sugarcane bagasse ash-coated PET-fibers. *Materials Today: Proceedings*, **48**, pp. 994–1000, 2022.
- [13] Sharma, T. & Singh, S., Influence of marble dust, bagasse ash and paddy straw fibers on the density and optimum water content of unfired soil block. *Materials Today: Proceedings*, **51**, pp. 965–971, 2022.
- [14] Subedi, S., Arce, G.A., Hassan, M.M., Barbato, M., Mohammad, L.N. & Rupnow, T., Feasibility of ECC with high contents of post-processed bagasse ash as partial cement replacement. *Construction and Building Materials*, **319**, 126023, 2022.
- [15] Wagh, M. & Waghe, U.P., Development of self-compacting concrete blended with sugarcane bagasse ash. *Materials Today: Proceedings*, 2022.
- [16] Wu, N., Ji, T., Huang, P., Fu, T., Zheng, X. & Xu, Q., Use of sugar cane bagasse ash in ultra-high performance concrete (UHPC) as cement replacement. *Construction and Building Materials*, **317**, 125881, 2022.
- [17] Amin, M., Zeyad, A.M., Tayeh, B.A. & Saad Agwa, I., Effects of nano cotton stalk and palm leaf ashes on ultrahigh-performance concrete properties incorporating recycled concrete aggregates. *Construction and Building Materials*, **302**, 124196, 2021.

- [18] Yousefi, M., Khandestani, R. & Gharaei-Moghaddam, N., Flexural behavior of reinforced concrete beams made of normal and polypropylene fiber-reinforced concrete containing date palm leaf ash. *Structures*, **37**, pp. 1053–1068. <https://linkinghub.elsevier.com/retrieve/pii/S2352012422000674>. Accessed on: 20 Feb. 2022.
- [19] Li, Q. et al., Effect of waste corn stalk ash on the early-age strength development of fly ash/cement composite. *Construction and Building Materials*, **303**, 124463, 2021.
- [20] Akhayere, E. & Kavaz, D., Synthesis of silica nanoparticles from agricultural waste. *Agri-Waste and Microbes for Production of Sustainable Nanomaterials*, pp. 121–138, 2022.
- [21] Cao, F., Qiao, H., Li, Y., Shu, X. & Cui, L., Effect of highland barley straw ash admixture on properties and microstructure of concrete. *Construction and Building Materials*, **315**, 125802, 2022.
- [22] Odeyemi, S.O. et al., Mechanical properties and microstructure of high-performance concrete with bamboo leaf ash as additive. *Cleaner Engineering and Technology*, **6**, 100352, 2022.
- [23] Bheel, N., Ali, M.O.A., Kirgiz, M.S., de Sousa Galdino, A.G. & Kumar, A., Fresh and mechanical properties of concrete made of binary substitution of millet husk ash and wheat straw ash for cement and fine aggregate. *Journal of Materials Research and Technology*, **13**, pp. 872–893, 2021.
- [24] Hamid, Z. & Rafiq, S., An experimental study on behavior of wood ash in concrete as partial replacement of cement. *Materials Today: Proceedings*, **46**, pp. 3426–3429, 2021.
- [25] Meko, B. & Ighalo, J.O., Utilization of Cordia Africana wood sawdust ash as partial cement replacement in C 25 concrete. *Cleaner Materials*, **1**, 100012, 2021.
- [26] Raketh, M. et al., Sulfate removal using rubber wood ash to enhance biogas production from sulfate-rich wastewater generated from a concentrated latex factory. *Biochemical Engineering Journal*, **173**, 108084, 2021.
- [27] Assiamah, S., Agyeman, S., Adinkrah-Appiah, K. & Danso, H., Utilization of sawdust ash as cement replacement for landcrete interlocking blocks production and mortarless construction. *Case Studies in Construction Materials*, **16**, e00945, 2022. <https://linkinghub.elsevier.com/retrieve/pii/S2214509522000778>. Accessed on: 21 Feb. 2022.
- [28] Tijani, M.A., Ajagbe, W.O. & Agbede, O.A., Combined reusing of sorghum husk ash and recycled concrete aggregate for sustainable pervious concrete production. *Journal of Cleaner Production*, 131015, 2022. <https://linkinghub.elsevier.com/retrieve/pii/S0959652622006503>. Accessed on :20 Feb. 2022.
- [29] Koyuncu, D.D.E. & Okur, M., Investigation of dye removal ability and reusability of green and sustainable silica and carbon-silica hybrid aerogels prepared from paddy waste ash. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **628**, 127370, 2021.
- [30] Elango, K.S., Remya, P.R., Vivek, D., Gopi, R., Rajeshkumar, V. & Saravanakumar, R., Strength and durability studies on ficus exasperata leaf ash concrete. *Materials Today: Proceedings*, **37**(Part 2), pp. 999–1002, 2021.
- [31] Al-Shwaiter, A., Awang, H. & Khalaf, M.A., Performance of sustainable lightweight foam concrete prepared using palm oil fuel ash as a sand replacement. *Construction and Building Materials*, **322**, 126482, 2022.
- [32] Shahbazpanahi, S. & Faraj, R.H., Feasibility study on the use of shell sunflower ash and shell pumpkin ash as supplementary cementitious materials in concrete. *Journal of Building Engineering*, **30**, 101271, 2020.
- [33] Oyeibisi, S., Igba, T., Raheem, A. & Olutoge, F., Predicting the splitting tensile strength of concrete incorporating anacardium occidentale nut shell ash using reactivity index concepts and mix design proportions. *Case Studies in Construction Materials*, **13**, e00393, 2020.
- [34] Kumar Yadav, A., Gaurav, K., Kishor, R. & Suman, S.K., Stabilization of alluvial soil for subgrade using rice husk ash, sugarcane bagasse ash and cow dung ash for rural roads. *International Journal of Pavement Research and Technology*, **10**(3), pp. 254–261, 2017. DOI: 10.1016/j.ijprt.2017.02.001.
- [35] Ekasila, S., Vishali, B. & Anisuddin, S., An experimental investigation on compressive

strength of concrete with rice husk and cow dung ash using various curing methods.
Materials Today: Proceedings, 2021.

[36] Abdul Razak, N.A., Othman, N.H., Mat Shayuti, M.S., Jumahat, A., Sapiai, N. & Lau, W.J., Agricultural and industrial waste-derived mesoporous silica nanoparticles: A review on chemical synthesis route. *Journal of Environmental Chemical Engineering*, **10**(2), 107322, 2022.

<https://linkinghub.elsevier.com/retrieve/pii/S2213343722001956>. Accessed on: 23 Feb. 2022.

[37] Sarkar, J. et al., Synthesis of nanosilica from agricultural wastes and its multifaceted applications: A review. *Biocatalysis and Agricultural Biotechnology*, **37**, 102175, 2021.

[38] Shukla, S.S., Chava, R., Appari, S.A.B. & Kuncharam, B.V.R., Sustainable use of rice husk for the cleaner production of value-added products. *Journal of Environmental Chemical Engineering*, **10**(1), 106899, 2022.

[39] Goodman, B.A., Utilization of waste straw and husks from rice production: A review. *Journal of Bioresources and Bioproducts*, **5**(3), pp. 143–162, 2020.