Uniosun Journal of Engineering and Environmental Sciences (UJEES), Vol. 8 No. 2, Sept., 2026
DOI: 10.64980/ujees.v8i2.037 **Akinleye et al.**
Published: September 30, 2026

COCONUT SHELL FIBRES AS NATURAL REINFORCEMENT IN CONCRETE PAVING UNITS: A REVIEW

M. T. AKINLEYE[1], E. O. AJADI[2*], O. A. HAMMED[3], A. A. ADEYINKA[4], O. S. OYEYIOLA[5], and B. SALAWU[6]

[1,2,3,4,5,6]*Department of Civil Engineering, Adeleke University, Ede, Nigeria.*

[*]*Corresponding Author: ajadi.emmanuel@adelekeuniversity.edu.ng*

Abstract
There is a rising demand for sustainable construction materials that has propelled research into use of natural fibre as reinforcement in concrete composites. This paper presents a review of mechanical performance of Coconut Shell Fibre (CSF) reinforced Interlocking Paving Stones (IPS) used for Road Construction Applications. The review covers the intrinsic properties of CSFs, such as tensile strength, aspect ratio, durability and water absorption, and how these properties affect their reinforcing ability in cementitious matrices. Special attention is given to the fibre-matrix bonding mechanisms, mechanical interlock, chemical adhesion (improved by alkali treatments), and crack-bridging capacities, which all help the composite to perform better. The paper assesses the effects of the dosages of the CSF on mechanical properties of the cement and shows that the optimum dosage range for CSF is 0.5% to 1.0% by weight of cement that can improve flexural strength and impact resistance of the cement, while beyond this range would affect workability and compressive strength. When comparing with other natural fibres like sisal, jute and coir, it can be observed that CSFs possess an optimum balance of mechanical efficiency, economics and environment friendliness, making them suitable for IPS applications in areas where coconut waste is available. Incorporating CSFs in IPS allows for better mechanical properties like toughness, flexural strength, and impact resistance while also being a step towards sustainable construction through the use of agricultural waste. These results help to place CSF-reinforced IPS as a viable eco-friendly solution for light traffic roadways and pedestrian pavements in line with the world's vision for green infrastructure development.

Keywords
Coconut Shell Fibre, Interlocking Paving Stones, Natural Fibre Reinforced Concrete, Mechanical Performance, Sustainable Road Construction

1.0 INTRODUCTION

As the global construction industry becomes more aware of the importance of sustainable development and environmentally friendly materials, increasing attention is been directed towards reducing the environmental impact of infrastructure development (Abera 2024; Adebanjo *et al*., 2025). Conventional concrete and synthetic reinforcements are used in traditional construction, providing good structural strength, but they are often linked to high carbon emissions, resource consumption, and non-biodegradable waste (Adekomaya and Majozi 2024; Singh *et al*., 2025). This has prompted a broad range of research for alternative materials that are both mechanically efficient and environmentally friendly. One of the promising innovations is the use of natural fibres as reinforcement materials in cement-based composites, which demonstrates potential improvements in material performance and eco-friendly construction methods (Ipaye *et al*., 2025; Mani *et al*., 2025). Recently, sustainable material innovations were developed for Interlocking Paving Stones (IPS), which is one of the most common paving solutions in the field of urban infrastructure, especially for roads, sidewalks, walkways, and parking lots (Akinleye *et al*., 2022; Okosun *et al*., 2023). The IPS is preferred due to the advantages of modular design, ease of installation, aesthetic beauty and functions well in the load distribution. Conventional IPS, however, is sometimes limited in its mechanical properties due to such problems as brittleness, crack propagation under dynamic loads, and low impact resistance (Akinleye *et al*., 2026). Incorporating natural fibres into IPS offers a potential approach to improving their mechanical properties while supporting sustainable construction goals (Bilir *et al*., 2022). Bio reinforcement of paving stones with fibres also contributes to enhanced ductility, energy absorption and post-cracking properties, which are essential for their durability and performance in response to fluctuating load conditions (Akbulut *et al*., 2025; Akinleye *et al*., 2026).

In various types of natural fibres examined, the Coconut Shell Fibres (CSF) which is produced as a by-product during the processing of coconut shell has been receiving a great interest because of the desirable physical and mechanical properties. Coconut shells are plentiful in tropical areas, especially in those nations that have a large coconut production industry (Mu *et al*., 2025). The use of CSF in concrete composites is a way of valorising waste, which is in line with the principles of circular economy and the use of agricultural waste as a resource for the construction industry. Previous studies have demonstrated the potential of coconut-derived materials to improve certain mechanical properties of concrete, particularly crack resistance and post-cracking performance (Odeyemi *et al*., 2024; Huang *et al*., 2026). However, their effectiveness depends on material characteristics, fibre dosage, interfacial bonding and resistance to moisture and alkaline degradation (Mutnbak, 2026). Despite these findings, evidence concerning the long-term performance of Coconut Shell Fibre (CSF)-reinforced interlocking paving stones (IPS) under repeated loading and outdoor exposure remains limited. Coconut Shell Fibres have the potential to be used in sustainable construction, allowing for the use of locally available agricultural waste and potentially reducing the need for traditional reinforcement materials (Poornachandhra *et al.,* 2023; Terra *et al.,* 2023). The economic and environmental advantages, however, depend on processing needs, fibre treatment, transportation and entire production costs. This review assesses the effects of the characteristics of the CSF, fibre–matrix bonding, amount and treatment on mechanical performance and durability of interlocking paving stones. It also reviews the drawbacks of the current research and research gaps with regard to the practical application and long-term performance of sustainable road construction.

2.0 FIBRE CHARACTERISTICS RELEVANT TO CONCRETE REINFORCEMENT

The coconut shell fibres (CSFs) have a variety of physical and mechanical properties that affect their use as reinforcement material in concrete composites (Martinelli *et al*., 2024). They are characterised, in large part, by their tensile strength, which can vary from 95 to 230 MPa depending on such factors as fibre source, treatment and preparation. This tensile strength capability allows CSFs to be able to contribute to the flexural strength and impact resistance of concrete by creating tensile reinforcement to span micro-cracks, distribute stresses and prevent sudden brittle failure. Due to their versatility in absorbing and redistributing tensile forces, CSFs are well suited for the use in pedestrian walkways, where paving stones are exposed to dynamic load and repetitive load, and for light traffic roads (Mutnbak, 2026).

The aspect ratio (the ratio of the fibres length and diameter) is another crucial variable determining the reinforcing effectiveness of CSF. Ideally, CSFs should have an aspect ratio between 30 and 60 to transfer the stresses in the concrete matrix optimally. A fibres aspect ratio that is too low will not ensure adequate bridging across cracks; a too high aspect ratio will cause poor dispersion and balling which will result in poor workability of the concrete mix (Rahman *et al*., 2023; Javadi Pordesari *et al*., 2025). Appropriately sized and shaped CSFs can help to achieve an appropriate aspect ratio that facilitates stress distribution and improve mechanical integrity of Interlocking Paving Stones (IPS). The CSFs, like most natural fibres, are hydrophilic, as they are made of lignocellulosic fibres which absorb water, making their water absorption rating high. If it is not managed well, this may have a negative impact on the workability of fresh concrete and the durability of the composite over the long term (Mishra and Basu, 2020; Dange and Gnanamoorthy, 2026). But, the durability of the fibres can be greatly enhanced by using chemical treatments like alkali treatment (NaOH) or silane coupling agents, which increases the fibre-matrix interfacial bonding and decreases the water absorption capacity of the fibres (Ahmad *et al*., 2021; Kumar and Saha, 2024). Such treatments change the surface properties of the CSFs to suit the alkaline environment of the cementitious materials used, thus providing good adhesion and enhanced mechanical properties with time.

Table 1: Essential Characteristics of Coconut Shell Fibres for Concrete Reinforcement

Characteristic	Typical Values/Details	Impact on Concrete Performance
Tensile Strength	80 – 250 MPa	Enhances flexural strength and impact resistance by bridging micro-cracks.
Aspect Ratio (L/D)	Optimal Range: 30 – 60	Ensures effective stress transfer and crack bridging within the concrete matrix.
Durability	Improved through alkali/silane treatments	Enhances fibre-matrix adhesion; reduces fibre degradation in alkaline environments.
Water Absorption	High (untreated); Reduced through chemical pre-treatments	Affects workability of fresh concrete; treatment reduces negative impact.
Surface Texture	Rough and irregular	Promotes mechanical interlock with cement paste, enhancing bonding.

Source: Martinelli *et al*., (2024); Mboungou Londe *et al*., (2024); Javadi Pordesari *et al*., (2025)

3.0 FIBRE-MATRIX BONDING MECHANISMS

The bond between fibres and the cementitious matrix is a key factor affecting the properties of fibre-reinforced composites. With coconut shell fibres, both mechanical interlocking and chemical bonding along with crack bridging ability are involved. The irregular surface texture of the CSFs from their natural fibrous structure is conducive to mechanical interlocking with the cement paste. This physical entanglement increases load transfer efficiency between the fibre and the matrix, which increases resistance to pull-out forces and helps create the tensile and flexural strengths of the material.

In addition to physical interlocking, chemical bonding is also a very important factor influencing the durability and strength of the fibre-matrix interface (Fong *et al*., 2025; Noman *et al*., 2026). The raw CSFs have poor chemical compatibility with the very alkaline conditions of cementitious materials (Gudayu *et al*., 2025). Alkali (NaOH) treatment and silane coupling agents are examples of surface treatments that greatly improve the fibre's reactivity. For instance, alkali treatment removes lignin, waxes and impurities, increasing the surface roughness of wood taking more hydroxyl groups which can react with the calcium silicate hydrates (C-S-H) of the cement. This chemical bonding increases adhesion and reduces fibre debonding, and in turn, results in improved mechanical performance.

An important role for the CSFs in the concrete matrix closes the microcracks (Amaguana *et al*., 2023). Under stress, cracks start to form and well-distributed CSFs intercept and check the propagation of the crack by preventing any tensile force on the crack faces. This crack-bridging action enables better toughness, ductility and post crack behaviour of the concrete which helps to absorb the energy and extend the life of the interlocking paving stones when subjected to repetitive loading (Dinkar and Kumar, 2025).

Table 2: Fibre-Matrix Bonding Mechanisms of Coconut Shell Fibres

Bonding Mechanism	Description	Impact on Concrete Performance
Mechanical Interlock	Rough, irregular surface texture creates physical interlocking with cement paste.	Improves load transfer, pull-out resistance, and tensile/flexural strength.
Chemical Bonding	Surface treatments (NaOH, silane) enhance chemical adhesion with C-S-H gel.	Strengthens fibre-matrix interface, reduces debonding, and enhances durability.
Microcrack Bridging	Fibres bridge across microcracks during stress loading.	Delays crack propagation, improves ductility and toughness of IPS.

Source: Mboungou Londe *et al*., (2024); Closse *et al*. (2024); Zaid and Ben Kahla (2026)

4.0 DOSAGE OPTIMIZATION AND WORKABILITY

The mechanical characteristics and workability of the composite have been found to be greatly influenced by the percentage of coconut shell fibres added to the concrete mix (fibre dosage) (Oyelowo *et al*., 2023; Javadi *et al*., 2025). When added at low concentrations (0.5% to 1.0% by weight of cement), CSFs have been demonstrated to enhance flexural strength, impact resistance and post-cracking toughness of the cement-based material without significantly adversely affecting the workability of the fresh cement-based material (Thapa *et al.,* 2026; Dabhade, and Ambadkar, 2026). This dosage range is frequently regarded as the best compromise on the mechanical improvements in relation to practical factors like mixing, casting, compaction etc.

But, when the fibre dose is more than 1.5% by weight of cement, problems start to arise. The higher the fibre content, the greater the chance of balling effects, which can cause fibres to bunch together, and making the fibre mix non-uniform (Pu *et al*., 2021; Oyelowo *et al*., 2023). This will not only lower the reinforcing efficiency of the fibres, but also make the concrete less workable and flowable. Poor dispersion of fibres causes the development of voids, low density and decrease in compressive strength because it increases the internal defects.

If a higher fibre content is used, it is necessary to add either superplasticizers or water reducing admixtures to help offset this effect and improve the workability. These admixtures enhance the workability of the mix and its cohesion to increase fibre dosage without compromising the workability needed for good compaction and finishing. Therefore, a meticulous balance between fibre content, mix design adjustments, and admixture dosage is crucial to harness the benefits of CSFs while maintaining a workable and structurally sound paving stone composite.

5.0 INFLUENCE ON MECHANICAL PROPERTIES

The experimental results indicate that the addition of Coconut Shell Fibres in concrete composites plays significant role in mechanical behaviour of Interlocking Paving Stones (IPS) material in terms of compressive strength, flexural strength, impact resistance.

Table 3: Effects of CSF Dosage on Concrete Performance and Workability

Fibre Dosage	Effects on Mechanical Properties	Impact on Workability
Low Dosage (0.5% – 1.0%)	Improves flexural strength, impact resistance, and toughness.	Minimal effect on workability; mix remains workable and uniform.
Higher Dosage (>1.5%)	May lead to fibre balling, non-uniform distribution; possible reduction in compressive strength.	Decreases workability significantly; increased risk of voids and poor compaction.
Workability Adjustment	Superplasticizers or water-reducing agents needed for higher fibre dosages.	Restores flowability and cohesion, allowing higher fibre content without defects.

Source: Garcia *et al*., (2024); Hashir *et al*., (2025)

i. Compressive Strength: The effect of the addition of CSFs on compressive strength is typically marginal or slightly negative because of the increased porosity and decrease in composite density that is introduced. Untreated CSFs may have a hydrophilic property, which can result in increased water absorption, water-cement ratio and quality of compaction of the mix. The compressive strengths, however, will be acceptable for structural applications in paving when the fibre content is optimized (0.5%–1.0% of the weight of cement), and when proper mixing procedures are used. Surface fibres also have a beneficial impact on these negative effects by improving fibre-matrix interface, decreasing porosity and achieving better fibre dispersion.

ii. Flexural Strength: One of the most remarkable advantages of CSF reinforcement is the notable boost in the flexural strength. Coconut fibres are micro-reinforcements which bridge the cracks and ensure the distribution of tensile stresses effectively across the matrix. It has been found in various studies that flexural strength can be raised by 10% to 25% due to the presence of CSFs which depend upon the length of fibres, dosage and treatment method. The advantage of this improvement is especially beneficial for IPS, where bending stresses may occur under load as a result of irregularities in the subgrade and vehicular traffic.

iii. Impact Resistance: In addition, CSF-reinforced IPS also show significant improvements in impact resistance, meaning it is able to absorb and disperse energy from sudden impacts. The fibres in the concrete matrix help to prevent cracking from spreading and spread out the energy spread over a wider area, minimising the risk of failure at a specific point. It is particularly useful for IPS to be used in low traffic pavements, walkways, and residential driveways where dynamic and impact loads due to foot traffic, bicycles, and light vehicles are common.

Table 4: Influence of CSFs on Mechanical Properties of IPS

Mechanical Property	Effect of CSF Inclusion	Remarks
Compressive Strength	Slight reduction due to increased porosity; remains acceptable with optimized dosage.	Treated fibres and proper mix design minimize strength loss.
Flexural Strength	Increases by 10%–25% due to crack-bridging and stress distribution mechanisms.	Key improvement area for CSF-reinforced IPS.
Impact Resistance	Enhanced capacity to absorb and dissipate impact energy.	Improves durability against dynamic loads, suitable for low-traffic roads.

Source: Gamage *et al*., (2022); Odeyemi *et al*., (2024); Huang *et al*., (2026)

6.0 COMPARISON WITH OTHER NATURAL FIBRES

In the context of other popular natural fibres, Coconut Shell Fibers (CSFs) offer a distinctive combination of mechanical properties, availability, and economic benefits, making them an attractive option for use in IPS road construction applications.

i. Sisal Fibres are well known for their very high tensile strength (400–700 MPa), much higher than that of CSFs. If so, however, sisal fibres have an inherent low level of crack-bridging capacity under dynamic or impact loading (Thomas and Jose, 2022). Furthermore, unlike coconut shells, sisal fibres are more expensive and less widely available in many tropical areas, which makes them more economically unviable for large scale application as paving materials.

ii. Jute Fibres, on the other hand, are appreciated for their workability due to their softness and ease of dispersion in concrete mixes. They tend to deteriorate quickly, however, if exposed to the alkaline environment of cementitious materials (Ahmad *et al*., 2022). They are not durable enough for long term use and are not suitable for outdoor use, such as in IPS, where durability in the presence of environmental exposure is important.

iii. Coir Fibres are also obtained from the husks of the coconut, but they have different structural properties compared to CSFs. Coir fibres tend to be longer and more flexible resulting in good tensile

performance. CSFs, however, have a coarser surface texture which dramatically improves mechanical interlocking with the cement matrix and contributes to greater crack resistance and fibre-matrix bonding. This helps to make CSFs more desirable for use in applications that require improved toughness and durability.

Each of the natural fibres is associated with certain benefits, while CSFs combine the best aspects of each fibre and provide a good balance of mechanical strength, cost and environmental friendliness, which makes them a competitive and viable choice for use in road construction projects, particularly in areas where there is a surplus of coconut waste.

Table 5: Comparative Analysis of CSFs with Other Natural Fibres for IPS Applications

Fibre Type	Tensile Strength	Durability in Concrete	Surface Texture (Bonding Efficiency)	Availability and Cost	Overall Suitability for IPS
Coconut Shell Fibres (CSF)	80–250 MPa	High (when treated)	Rough (excellent mechanical interlock)	Abundant and low-cost	Balanced performance, eco-friendly
Sisal Fibres	400–700 MPa	Good durability but brittle behaviour	Moderate	Costlier, less abundant in many regions	High strength but brittle, costly
Jute Fibres	200–350 MPa	Poor durability in alkaline environments	Smooth (limited interlocking)	Readily available but short lifespan	Easy to mix but unsuitable for IPS
Coir Fibres	100–250 MPa	Good, with pre-treatment	Smooth-flexible, less interlocking	Abundant in coconut-producing regions	Flexible but less interlock efficiency

Source: Labib (2022); Ahmad et al. (2022); Gamage et al. (2022); Martinelli et al. (2024)

7.0 CONCLUSION

The use of Coconut Shell Fibres in Interlocking Paving Stones is a promising green solution in the construction industry. Besides usage of CSFs for enhancing the mechanical performance of IPS such as flexural strength, toughness and impact resistance, it also helps in solving the pressing environmental concerns. This not only reduces reliance on synthetic fibres which are non-renewable, but also helps minimize the environmental impact of the built environment by using a waste product of farming operations, coconut shells.

However, there are some technical limitations, such as the reduction in workability, fibre dispersion issues, and slight sacrifices in strength, that should be addressed. These restrictions are not impenetrable, though. The negative effects on fresh concrete properties can be effectively minimised by using optimised mix designs, fibre treatment methods (e.g. alkali or silane treatment of the surface of the fibres) and the use of superplasticizers. A controlled fibre dosage of 0.5% to 1.0% by weight of cement, allows the benefits of the CSFs without compromising the workability or structure of the paving stones.

Furthermore, CSFs possess a combination of mechanical efficiency, economic viability and durability which is found to be a suitable balance when compared to other natural fibres such as Sisal, Jute and Coir, making them a suitable fibre for sustainable infrastructure development in tropical and developing countries where coconut waste is readily available. The enhanced crack bridging properties and impact energy absorption/dissipation properties of CSF-reinforced IPS are suitable applications for low traffic roads, pedestrian paths, residential driveways, and green landscaping. Finally, the CSF-reinforced IPS material has the potential to revolutionize the construction industry by offering an innovative and sustainable solution to conventional paving materials, while also being cost-effective. Additional studies on large-scale application techniques, durability testing, and field testing will assist in the wider adoption and scaling of the use of this in infrastructure projects and help toward reaching the goals of sustainable development around the world.

REFERENCES

[1] Abera, Y. A. (2024). Sustainable building materials: A comprehensive study on eco-friendly alternatives for construction. *Composites and Advanced Materials*, *33*, 26349833241255957.

[2] Adebanjo, A. U., Shafiq, N., Kumar, V., Olatoyan, O. J., Abd Razak, S. N., and Yusof, N. F. (2025). Innovative Green Infrastructure Initiatives for Development in the Construction Industry. In *Sustainable Green Infrastructure: Materials and Technologies* (pp. 121-138). Singapore: Springer Nature Singapore.

[2] Adekomaya, O., and Majozi, T. (2024). Sustainable reclamation of synthetic materials as automotive parts replacement: effects of environmental response on natural fiber vulnerabilities. *Environmental Science and Pollution Research*, *31*(12), 18396-18411.

[4] Ahmad, J., Arbili, M. M., Majdi, A., Althoey, F., Deifalla, A. F., and Rahmawati, C. (2022). Performance of concrete reinforced with jute fibers (natural fibers): A review. Journal of Engineered Fibers and Fabrics, 17, Article 15589250221121871.

[5] Ahmad, R. K., Sulaiman, S. A., Dol, S. S., and Umar, H. A. (2021). The potential of coconut shells through pyrolysis technology in Nigeria. In *Clean Energy Opportunities in Tropical Countries* (pp. 151-175). Singapore: Springer Singapore.

[6] Akbulut, Z. F., Tawfik, T. A., Smarzewski, P., and Guler, S. (2025). Advancing Hybrid Fiber-Reinforced Concrete: Performance, Crack Resistance Mechanism, and Future Innovations. *Buildings*, *15*(8), 1247.

[7] Akinleye, M. T., Tijani, M. A., Salami, L. O., Joseph, O. P., Salami, M. O., and Ogungbola, O. I. (2022). Mechanical performance of interlocking paving stone using dissolved waste plastics. *FUOYE Journal of Innovation, Science and Technology*, *2*(1), 66–72.

[8] Akinleye, M. T., Yusuff, R. O., Daramola, O. G., Adebanjo, E. O., Ajadi, E. O., Adewoyin, V. A., and Salawu, B. (2026). Design standards and performance requirements for interlocking paving stones in road construction: A review. *Adeleke University Journal of Engineering and Technology, 9*(1), 227 – 240.

[9] Amaguana, M., Guamán, L., Gómez, N. B. Y., Khorami, M., Calvo, M., and Albuja-Sánchez, J. (2023). Test method for studying the shrinkage effect under controlled environmental conditions for concrete reinforced with coconut fibres. Materials, 16(8), Article 3247.

[10] Bilir, T., Aygun, B. F., Shi, J., Gencel, O., and Ozbakkaloglu, T. (2022). Influence of different types of wastes on mechanical and durability properties of interlocking concrete block paving (ICBP): a review. *Sustainability*, *14*(7), 3733.

[11] Closse, A., Onesippe Potiron, C., Arsene, M.-A., and Bilba, K. (2024). Assessment of vegetable fiber-matrix adhesion and durability, in cement-based and polymer-based composite: Principles from literature review. Journal of Composite Materials, 58(7).

[12] Dabhade, P., and Ambadkar, S. (2026). Reinforcing resilience: a review of hybrid fibre effects on concrete's mechanical and impact characteristics. *Journal of Building Pathology and Rehabilitation*, *11*(2), 90.

[13] Dange, D., and Gnanamoorthy, R. (2026). Influence of moisture absorption on coir fibre strength and interfacial adhesion with polymer matrix. *Composite Interfaces*, 1-17.

[14] Dinkar, V. C., and Kumar, V. (2025). A review study on the mechanical behaviour of natural fibre-reinforced epoxy composite. *Polymer Bulletin*, 1-36.

[15] Fong, A., Wong, D. H., Lau, S., Debnath, S., Anwar, M., Davies, I. J., and Johar, M. B. (2025). A review on the hybrid polymer composites comprising natural fibre and nanomaterial reinforcement. *Journal of Composite Materials*, 00219983251334861.

[16] Gamage, S., Palitha, S., Meddage, D. P. P., Mendis, S., Azamathulla, H. M., and Rathnayake, U. (2022). Influence of crumb rubber and coconut coir on strength and durability characteristics of interlocking paving blocks. Buildings, 12(7), Article 1001.

[17] Garcia, G., Cabrera, R., Rolón, J., Pichardo, R., and Thomas, C. (2024). Natural fibers as reinforcement of mortar and concrete: A systematic review from Central and South American regions. Journal of Building Engineering, 98, Article 111267.

[18] Gudayu, A. D., Getahun, D. E., Mekuriaw, D. M., Walelign, F. T., and Ahmed, A. S. (2025). Natural fiber reinforced cementitious composites; materials, compatibility issues and future perspectives. Composite Interfaces, 32(3), 363-397.

[19] Hashir, Ahmed, A., Memon, M. A., Javed, M. U., and Memon, B. A. (2025). Evaluation of fresh properties and compressive strength of self-compacting concrete reinforced with coir fibers and modified with chemical admixtures. Journal of Applied Engineering Sciences, 15(1), 105–112.

[20] Huang, F., Peng, D., Zhao, Y., Zhao, G., and Fu, S. (2026). Effects of coconut shell ash and coir fiber on the mechanical properties and microstructure of concrete. *Buildings*, *16*(5), 1063.

[21] Ipaye, M. A., Alomaja, J. A., Joseph, O. P., Akinleye, M. T., Oyewo, S. T., Oyelowo, M. O., ... and Adeleke, J. A. (2025). Compressive and Tensile Strength Performance of Chicken Feather-Reinforced Concrete Incorporating Milled Palm-Kernel Shell as Partial Replacement for Fine Aggregate Pp 271 – 278.

[22] Javadi Pordesari, A., Shafigh, P., Ünal, M. T., and Ibrahim, Z. (2025). Mechanical Properties of Coconut Shell Lightweight Aggregate Concrete: A Comprehensive Review. *Advances in Civil Engineering*, *2025*(1), 7816362.

[23] Kumar, S., and Saha, A. (2024). Utilization of coconut shell biomass residue to develop sustainable biocomposites and characterize the physical, mechanical, thermal, and water absorption properties. *Biomass Conversion and Biorefinery*, *14*(12), 12815-12831.

[24] Labib, W. A. (2022). Plant-based fibres in cement composites: A conceptual framework. Journal of Engineered Fibers and Fabrics, 17, Article 15589250221078922.

[25] Mani, S., Partheeban, P., and Gifta, C. (2025). A comprehensive review on multilayered natural-fibre composite reinforcement in geopolymer concrete. *Cleaner Materials*, 100310.

[26] Martinelli, F. R. B., Pariz, M. G., de Andrade, R., Ferreira, S. R., Marques, F. A., Monteiro, S. N., and de Azevedo, A. R. G. (2024). Influence of drying temperature on coconut-fibers. Scientific Reports, 14, Article 6421.

[27] Mboungou Londe, G. H., Mwero, J. N., Kanali, C., and Abuodha, S. O. (2024). Investigating the influence of raw and treated coconut fibre obtained from agricultural residue on the strength and durability characteristics of high-strength concrete. Advances in Civil Engineering, 2024, Article 8275876.

[28] Mishra, L., and Basu, G. (2020). Coconut fibre: its structure, properties and applications. In *Handbook of natural fibres* (pp. 231-255). Woodhead Publishing.

[29] Mu, Z., Peng, H., Jayarathna, S. P., Indrachapa, M. T., Yang, C., Yang, S., ... and Luo, J. (2025). The coconut palm in China: distribution, germplasm, and sustainable development through genomic and biotechnological approaches. *Technology in Horticulture*, *5*(1), Article number: e005 (2025).

[30] Mutnbak, M. (2026). Coconut Shell Aggregate and Coir Fiber in Cement Concrete: A Review of Mechanical Performance, Durability, and Sustainability Under Functional Equivalency. *Polymers*, *18*(11), 1383.

[31] Noman, M. T., Amor, N., Azeem, M., and Hussain, F. (2026). Fiber–Matrix interface engineering in polymer composites: Linking surface chemistry to multiscale mechanical performance. *Polymers*, *18*(15), 1842.

[32] Nwankwo, E. I., Onyegirim, S. N., Owuama, K. C., and Onyenanu, I. U. (2025). Traditional vs. Modern Coconut Oil Extraction: A Systematic Review of Practices and Outcomes. *IPS Journal of Engineering and Technology*, *1*(2), 91-100.

[33] Odeyemi, S. O., Shitu, A., and Adisa, M. O. (2024). Impact resistance of coconut fibre-reinforced concrete. Journal of Engineering Research, 29(2), 14–21.

[34] Okosun, A. E., Okeke, F. O., Igwe, A. E., and Ezema, E. C. (2023, September). Transit, walking and cycling infrastructure and sustainable development in Enugu city, Nigeria. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1239, No. 1, p. 012022). IOP Publishing.

[35] Oyebisi, S., Arab, Y., Akinleye, M., Alquraish, M., and Oladipupo, S. (2026). Mechanical properties of concrete reinforced with Elaeis Guineensis midrib fibres. *Scientific Reports, Article 27610*.

[36] Oyelowo, M. O., Alomaja, J. A., Akinleye, M. T., Joseph, O. P., Salami, L. O., and Oluokun, G. O. (2023). Performance of concrete with partial replacement of fine aggregate with finely milled palm kernel shell (FMPKS). In *Proceedings of the 2nd International Conference on Advances in Cement and Concrete Research*, pp. 20–27.

[37] Poornachandhra, C., Jayabalakrishnan, R. M., Balasubramanian, G., Lakshmanan, A., Selvakumar, S., Maheswari, M., and John, J. E. (2023). Coconut husk fiber: A low-cost bioresource for the synthesis of high-value nanocellulose. *Biointerface Res. Appl. Chem*, *13*, 504.

[38] Pu, B. C., Liu, B., Li, L., Pang, W., and Wan, Z. (2021). Influence of polypropylene fibre factor on flowability and mechanical properties of self-compacting geopolymer. *Materials*, *14*(17), 5025.

[39] Rahman, K. A., Leman, A. M., and John, F. I. T. (2023). The Production of Briquette Charcoal from Coconut Shell and Palm Shell as A Renewable Energy Source. *International Journal of Technical Vocational and Engineering Technology*, *4*(1), 1-12.

[40] Singh, S., Kumari, R., and Kamble, Z. (2025). Sustainable bio-based smart and intelligent composites: A review. *Journal of Reinforced Plastics and Composites*, 07316844251410428.

[41] Terra, I. C. D. C., Batista, F. G., Silva, D. W., Scatolino, M. V., Alves Júnior, F. T., Martins, M. A., and Mendes, L. M. (2023). Mining waste and coconut fibers as an eco-friendly reinforcement for the production of concrete blocks. *Environmental Science and Pollution Research*, *30*(22), 62641-62652.

[42] Thapa, I., Poudel, B., Subedi, R., Adhikari, S., Shrestha, G., & Magar, P. R. (2026). Physics-Informed Neural Network Framework for Predicting Compressive Strength of Coconut Fiber Reinforced Concrete.

[43] Thomas, B. C., and Jose, Y. S. (2022). Impact of sisal fiber reinforced concrete and its performance analysis: A review. *Evolutionary Intelligence*, *15*(2), 865-875.

[44] Zaid, O., and Ben Kahla, N. (2026). Natural fiber reinforcements in cement-based composites: A review on recent advances, properties, and sustainability. Industrial Crops and Products, Article 122520.