International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 48 No. 1 Mar. 2026, pp. 32-40

http://www.ijias.issr-journals.org/

Development and Physico-Mechanical Characterization of an Innovative Ternary Composite Based on Low-Density Polyethylene Waste, Sanaga Sand, and Coconut Shell Powder Using an Artisanal Process for Sustainable Construction

Kontchou Herman Fredy[1], Kenmeugne Bienvenu[1], Annouar Djidda Mahamat[2], Tchikdje Kouekem Marthe Prudence[3], and Essome Mbang Jonas Peequeur[4]

[1]Department of Industrial and Mechanical Engineering, National Advanced School of Engineering, University of Yaoundé I, Cameroon

[2]Faculty of Exact and Applied Sciences, University of Ndjamena, Chad

[3]Pôle de recherche, de l'Innovation et l'Entrepreneuriat (PRIE), Institut Universitaire de la Cote, Douala, Cameroon

[4]Centre d'Etudes sur les Changements Climatiques et la Mobilité (CECAM), Douala, Cameroon

ABSTRACT: Faced with the proliferation of plastic waste (LDPE), the overexploitation of Sanaga sand, and the under-utilization of coconut husks in Cameroon, this study developed and characterized an innovative ternary composite. The aim was to establish an artisanal manufacturing process and optimize the proportions of Low-Density Polyethylene (LDPE) waste, Sanaga sand, and coconut husk powder for sustainable construction. The process, inspired by ecological paving, tested nine formulations (LDPE 20-40%, sand/coconut 0-10%). Samples were characterized for their apparent density, water absorption rate, and mechanical properties (bending). Results showed a decrease in density with LDPE and coir powder. Water absorption remained very low (max. 0.640%), guaranteeing excellent durability in damp conditions. Although maximum flexural strength was lower than for thermo-compressed composites (probably due to the absence of pressure compaction in the artisanal method), the incorporation of coir conferred a certain ductility. Some formulations (F0/40, F5/20) are potentially usable for T4/T5 or T5 type pavers, and indoor flooring (P2). Future optimization will include pressure compaction and improvement of the LDPE/coconut interface to enhance performance. This work contributes to sustainable waste management and the promotion of environmentally-friendly building materials.

KEYWORDS: Coconut Shell Powder, Composite, Low-Density Polyethylene (LDPE), Sanaga Sand, sustainable construction.

1 INTRODUCTION

Plastics have profoundly transformed our daily lives, offering lightness, low cost, and versatility to many sectors. However, this success has led to a massive proliferation, turning these non-biodegradable materials into a major environmental burden. In Cameroon, this issue is particularly acute, notably in the Littoral region where the city of Douala generates up to 600,000 tons of plastic waste annually. These residues, with a lifespan potentially reaching 500 to 1000 years for bags, pose a severe threat to ecosystems and public health. Simultaneously, the country faces the overexploitation of natural re- sources such as Sanaga sand, whose artisanal extraction causes significant environmental degradation, including species disappearance and soil/water pollution. Furthermore, agricultural waste, like coconut shells, is underutilized, and its incineration contributes to carbon dioxide emissions. This context highlights the urgent need to develop circular approaches to transform these wastes into valuable resources, especially for sustainable construction applications.

Numerous studies have focused on valorizing plastic waste as a primary component in construction materials, largely in the form of binary composites.

Plastic-sand composites have been extensively investigated, confirming their potential for manufacturing various elements like tiles, bricks, and interlocking pavers. For instance, initial work [1] demonstrated the feasibility of such composites, identifying a formulation that achieved a compressive strength of 13.1 MPa. Subsequent research emphasized the critical role of the processing method [2]. By exploring manual versus thermo-compression techniques, one study showed a significant strength improvement with thermo-compression (up to 22.6 MPa in flexural strength) and a further increase with the addition of clay (up to 34.9 MPa). These findings confirm that process optimization, including precise parameter control [3, 4] for temperature and composition, is fundamental to enhancing the final mechanical properties.

Concurrently, researchers have explored the integration of natural fibers to further modify and improve performance. Binary plastic-coconut shell composites have garnered particular interest: a prior study [5] successfully produced composite rafters from crushed coconut shells and LDPE waste, reporting an impressive maximum flexural strength of 33.30 MPa at a 35% plastic content. More broadly, other characterization studies [6, 7, 8] confirm the general trend that the inclusion of coconut fibers enhances certain mechanical or thermal properties, though this is often accompanied by a reduction in overall stiffness (Young's Modulus), a common trade-off when using natural fibers [9].

Despite the documented valorization of plastic waste with either sand or coconut shells, our literature review reveals a significant novelty in the proposed approach. Currently, no exhaustive study has focused on the elaboration and characterization of a ternary composite specifically combining Low-Density Polyethylene (LDPE) waste, Sanaga sand, and coconut shell powder. The originality of this work also lies in adopting an artisanal manufacturing method. Existing studies have mainly favored binary composites or industrial processes requiring specialized equipment (extrusion, thermo-compression) [2, 3]. The exploration of this novel composition, coupled with a simplified and accessible manufacturing method, constitutes an unexplored and innovative research field for the development of eco-friendly building materials, ad- dressing the needs of contexts with limited techno- logical means [10, 11].

To address this overall challenge, the specific objectives of this research were:

1) develop an artisanal elaboration process for the ternary composite;
2) optimize the mass proportions of the three constituents to achieve the best performance;
3) characterize the physical (apparent density, water absorption rate) and mechanical properties (3-point flexural strength, strain at break, Young's modulus) of the artisanally produced composites;
4) evaluate the suitability of this new composite as a construction material by comparing its properties with existing standards and materials.

2 Materials And Methods

2.1 Raw Materials

The materials used in this study are Low-Density Polyethylene (LDPE) waste, Sanaga sand, and coconut shell powder.

- **LDPE Waste:** Collected from a company in Douala, Cameroon. It primarily consists of LDPE, which was washed to remove impurities before use. LDPE is widely used for packaging, making it an abundant waste material (figure 1).

Fig. 1. LDPE Waste collected for the composite elaboration

- **Sanaga Sand**: Sourced from the Sanaga river in Cameroon, it is commonly used in local construction. It was sieved through a 1 mm sieve to obtain a particle size below 1 mm (figure 2).

Fig. 2. Sanaga Sand (a) Raw sand (b) Sieved sand (d < 1mm)

- **Coconut Shell Powder:** Coconut shells were collected from vendors on the Douala-Yaoundé road. They were crushed to obtain coarse particles, then sieved through a 1 mm sieve to ensure a particle size below this limit (figure 3).

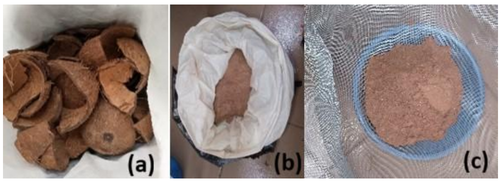

Fig. 3. Coconut Shell Powder: (a) Raw shells, (b) Crushed particles, (c) Sieved powder (d < 1mm).

2.2 Composite Formulations

Nine composite formulations were elaborated based on prior studies. The mass proportions of the constituents (LDPE, sand, and coconut shell powder) were varied as shown in Table 1. Percentages are calculated relative to the total mass of the composite.

Table 1. Mass proportions of the nine composite formulations

Formula	LDPE (%)	Sand (%)	Coconut (%)
F0/20	20	80	0
F0/30	30	70	0
F0/40	40	60	0
F5/20	20	75	5
F5/30	30	65	5
F5/40	40	55	5
F10/20	20	70	10
F10/30	30	60	10
F10/40	40	50	10

2.3 Artisanal Elaboration Process

The process (figure 4) is inspired by the artisanal method of manufacturing ecological pavers, utilizing a hybrid sand and coconut shell powder filler. The detailed steps are:

Preheating: A pot containing 20 ml of used engine oil was heated for 15 minutes to prepare for the LDPE melting.

1. Plastic Melting: The pre-weighed LDPE was gradually introduced into the pot and stirred for approximately 20 minutes to ensure complete and homogeneous melting.
2. Hybrid Filler Preparation: The Sanaga sand and coconut shell powder (both sieved at 1 mm) were pre-mixed together.
3. Component Mixing: The sand/coconut mixture was progressively incorporated into the molten plastic and stirred for 15 minutes to obtain a homogeneous composite.
4. Molding and Cooling: The resulting homogeneous paste was poured into standardized molds (dimensions 80×40×40 mm3). The samples were demolded after solidification by cooling at ambient temperature (10-30 minutes).

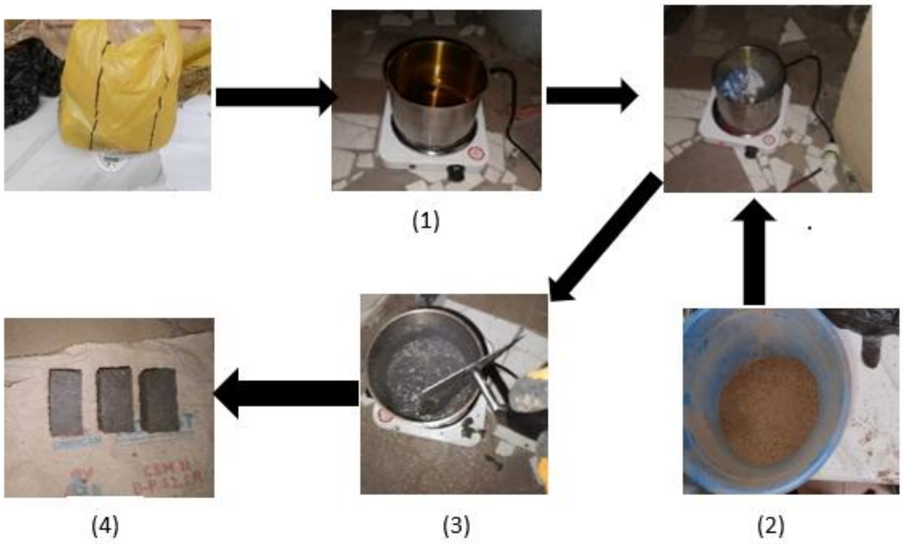

Fig. 4. Key stages of the artisanal elaboration process

2.4 Sample Characterization

The physical and mechanical properties were determined by the following tests:

- **Apparent Density (ρ_{App}):** Calculated from the mass (M) and volume (V) (measured with a caliper), according to the formula:

$$\rho_{App} = \frac{M}{V} \qquad (1)$$

Fig. 5. Apparent Density test

- **Three-Point Bending Test:** Performed according to the NF EN ISO 178 standard. Five samples per formulation (dimensions 80 × 10 × 5 mm3) were tested. The flexural strength (σf), strain at break (εf), and Young's modulus (Ef) were calculated from the load-deflection curves.

Fig. 6. Three-Point Bending Test (a) 3-point bending test samples (b) Sample on the machine

- **Water Absorption Rate:** The immersion absorption test was conducted according to standard NBN B 15-215: 1989. Samples were immersed in tap water at 20 ± 2 C for 24 hours.

  The absorption rate was calculated as:

  $$\text{Absorption (\%)} = \frac{M_{\text{wet}} - M_{\text{dry}}}{M_{\text{dry}}} \times 100 \qquad (2)$$

  where M_{wet} is the wet mass and M_{dry} is the initial dry mass.

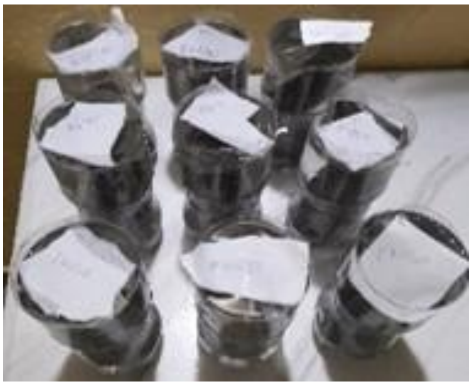

Fig. 7. Absorption Test

3 Results And Discussion

3.1 Physical Properties

- **Apparent Density:** the results show a nearly linear decrease in ap- parent density (with correlation coefficients R2 > 0.996) as the LDPE proportion increases across all series (0%, 5%, and 10% coconut shell powder). This is consistent with the lower intrinsic density of LDPE compared to the fillers. A global lowering of density is also observed with the addition of coconut shell powder. For 20% LDPE, the density decreases from 1689 kg/m3 (0% coconut) to 1599 kg/m3 (10% coconut), while for 40% LDPE, it drops from 1473 kg/m3 (0% coconut) to 1279 kg/m3 (10% coconut).

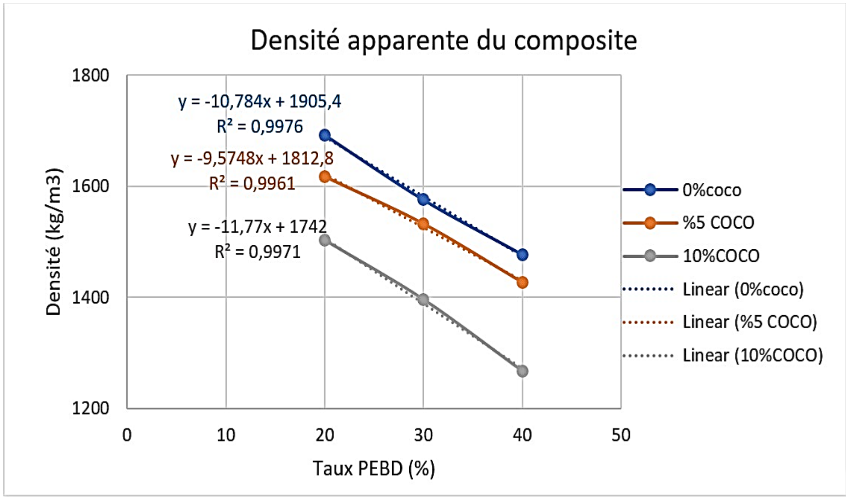

Fig. 8. Apparent Density as a function of LDPE content for different coconut powder proportions (Based on the text: showing quasi-linear decrease with increasing LDPE)

- **Water Absorption Rate:** the water absorption rate generally decreases as the LDPE content increases, regardless of the coconut shell powder proportion. For 0% coconut, the rate drops from 0.509% (20% LDPE) to 0.148% (40% LDPE). Conversely, the absorption rate slightly increases with the proportion of coconut shell powder. Samples with 10% coconut exhibited the highest absorption rates for the same LDPE content, with a maximum recorded at 0.640% (10% coconut, 20% LDPE). These values remain very low, below the 6% limit typically required for pavers (NBN B15-001).

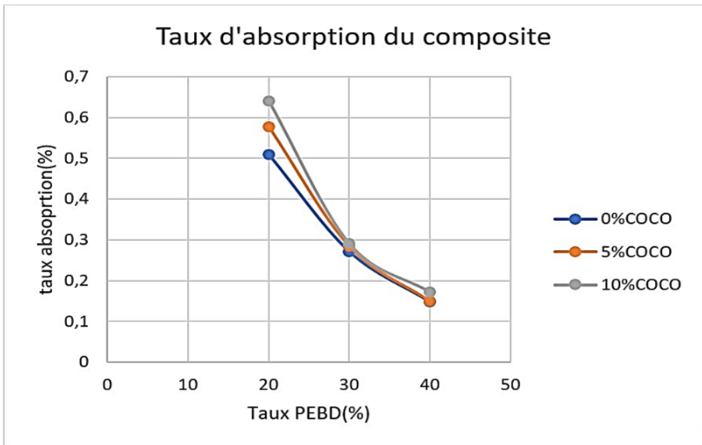

Fig. 9. Water Absorption Rate as a function of LDPE content for different coconut powder proportions (Based on the text: showing general decrease with in- creasing LDPE, and slight increase with increasing coconut)

3.2 MECHANICAL PROPERTIES (FLEXURAL TEST)

- **Flexural Strength (σ_f):** the flexural strength generally decreases as the coconut content increases. The maximum strength is 4.139 MPa at 0% coconut (40% LDPE), compared to 3.812 MPa at 5% coconut (20% LDPE) and 2.633 MPa at 10% coconut (30% LDPE). A peak behavior is observed as a function of the LDPE percentage, suggesting an optimal balance between the LDPE matrix and the fillers for stress transfer.

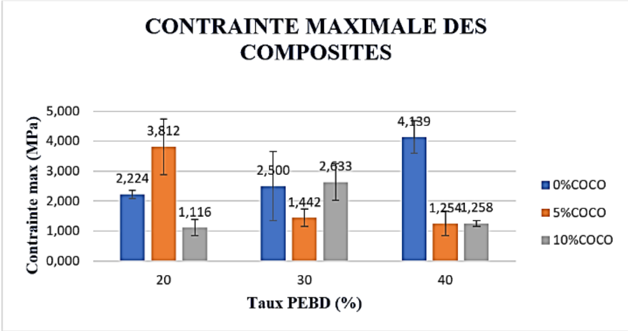

Fig. 10. Flexural Strength (σf) as a function of LDPE content for different coconut powder proportions (Based on the text: showing a peak behavior and a global decrease with increasing coconut)

- **Strength Strain at Break (εf):** the strain at break generally increases with the percentage of LDPE (due to its ductility). The highest value recorded is 6.938% (10% coconut, 30% LDPE). The coconut shell powder content also tends to increase the deformation up to an optimum. This enhancement of ductility is a beneficial characteristic for civil engineering applications.

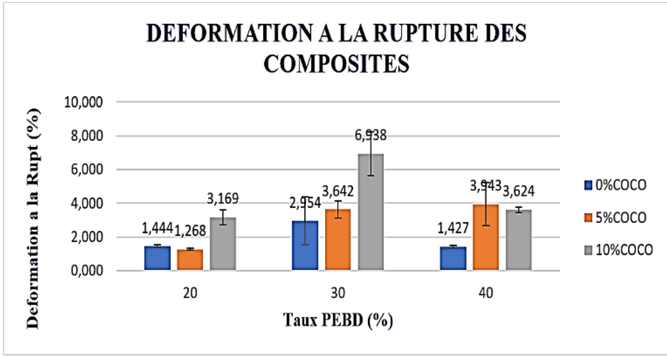

Fig. 11. Strain at Break (εf) as a function of LDPE content for different coconut powder proportions (Based on the text: showing general increase with increasing LDPE and a maximum around 30-40% LDPE)

- **Young's Modulus (Ef):** the Young's modulus decreases drastically as the coconut shell powder content increases. The values for 5% and 10% coconut are very low compared to the 0% coconut series (which reached a peak of 610.782 MPa at 40% LDPE). This reduction indicates a decrease in stiffness and an increase in flexibility of the composite due to the soft, porous nature of the vegetable fiber.

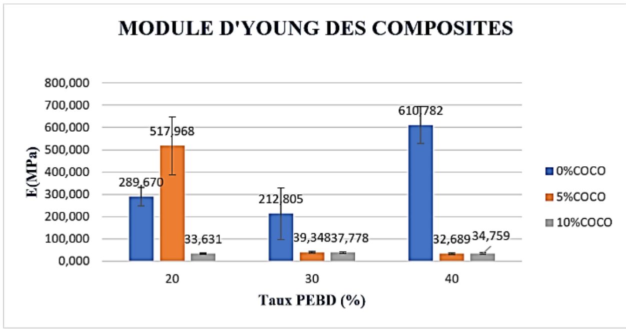

Fig. 12. Young's Modulus (Ef) as a function of LDPE content for different coconut powder proportions (Based on the text: showing a drastic decrease with in- creasing coconut content)

3.3 Discussion

The nearly linear decrease in apparent density with increasing LDPE content, coupled with a global decrease upon adding coconut shell powder, con rms the lightweight nature of the LDPE matrix (0.90 to 0.93 g/cm3) and the intrinsic low density of coconut fiber [9, 7]. This makes the resulting composite a promising candidate for lightweight construction materials.

The measured water absorption rates are remarkably low (maximum 0.640%). This result is significantly lower than the values reported for conventional cement or concrete materials and far below the 6% limit often imposed for pavers (NBN B15-001). This con rms the excellent waterproof ng capacity provided by the continuous LDPE matrix, similar to the work of [3, 11] on plastic-sand composites. The slight increase in absorption with coconut content, especially at 10%, is attributed to the presence of porous organic material, which tends to absorb water, a phenomenon commonly observed in natural fiber composites [8]. However, the LDPE encapsulation effectively minimizes this effect.

Regarding mechanical performance, the flexural strength obtained (maximum 4.139 MPa) is a critical point for discussion. This value is substantially lower than:

- The 22.6 MPa (flexural strength) obtained for thermo-compressed plastic-sand-clay composites [2].
- The 33.30 MPa (flexural strength) for LDPE-coconut rafters [5].

This lower performance is primarily and directly attributed to the artisanal fabrication process, specifically the absence of pressure compaction during molding and solidification. The importance of pressure in reducing porosity and ensuring optimal contact between the molten plastic and the fillers (sand and coir) is well documented in literature [2, 12]. The artisanal process, while accessible, results in a composite with higher internal porosity, leading to reduced stress transfer capacity and premature failure, regarding the uniformity of the mixture [4].

The incorporation of coconut shell powder leads to a significant reduction in the Young's Modulus (stiffness), this outcome aligns with previous literature on natural fiber-reinforced systems [9, 6]. However, this reduction in stiffness is accompanied by an increase in strain at break (ε_f) and ductility (max. 6.938%). This enhanced flexibility is beneficial for construction applications exposed to thermal fluctuations or slight ground movements, improving the material's tolerance to deformation before fracture.

3.4 Applications

Regarding their practical suitability, the mechanical performance of the developed composites was evaluated against established construction standards. Despite exhibiting lower flexural strength than traditional industrial materials, formulations F0/40 (4.139 MPa) and F5/20 (3.812 MPa) demonstrate significant potential for specific structural and architectural applications.

Although a study on compressive strength still needs to be conducted, in accordance with the NF EN 1339 standard for paving units, F0/40 complies with the requirements for both T4 and T5 type pavers (which require flexural strengths of ≥ 4 MPa and ≥ 3.5 MPa, respectively), while F5/20 satisfies the criteria for T5 pavers. Furthermore, formulation F0/40 meets the mechanical threshold (> 4 MPa) defined by the NF DTU 52.1 P1-2 standard for P2 category interior flooring, suitable for low-stress environments [2, 10, 13].

4 Conclusion

This study successfully established an accessible artisanal process for developing an innovative ternary composite based on LDPE waste, Sanaga sand, and coconut shell powder, and characterized its physico-mechanical properties across nine formulations. The results confirmed the excellent low water absorption (max. 0.640%), which is a major advantage for material durability in wet environments, largely exceeding the performance of traditional building materials. Although the mechanical performance, notably the flexural strength (max. 4.139 MPa), was limited compared to industrial composites due to the absence of pressure compaction in the artisanal method, the material exhibited significant ductility and could be classified as an acceptable paving material (T4/T5 or T5 type) or interior flooring (P2) for certain formulations. The incorporation of coconut shell powder was found to reduce stiffness but increase ductility, which is desirable in civil engineering applications where flexibility is beneficial. This work provides an accessible and immediate solution for waste valorization in contexts with limited technology. Future research should focus on optimizing the artisanal process by integrating a simple compaction step and applying surface treatments to the coconut shell powder [14] to improve the polymer/fiber interface, thereby maximizing the mechanical strength of this environmentally friendly material.

References

[1] R. Rakotosaona, J.d. D.Ramaroson, M. Mandimbisoa, J. O. Andrianaivoravelona, P. Andrianary, F. Randrianarivelo, and L. Andrianaivo, Valorisation l'échelle pilote des d chets plastiques pour la fabrication de mat riaux de construction, Madarevues, 2014. [Online]. Available: http://45.92.109.204/madarevues/?Valorisation-a-l-echelle-pilote-des-dechets-plastiques-pour-la-fabrication-de.

[2] B. Traore, Elaboration et caractérisation d'une structure composite (sable et déchets plastiques recycl s): Amélioration de la résistance par des charges en argiles, Th se de Doctorat, Université Bourgogne Franche- Comté; Université Felix Houphou t-Boigny, Abidjan, 2018. [Online]. Available: https://theses.hal.science/tel-02088767.

[3] A. Kumi-Larbi Jnr, R. Galpin, S. Manjula, Z. Lenkiewicz, and C. Cheeseman, Reuse of waste plastics in developing countries: Properties of waste plastic-sand composites, Waste and Biomass Valorization, vol. 13, no. 7, pp. 3821 3834, 2022.

[4] R. Kumar, S. B. Singh, S. Chauhan, and S. Dagar, A comprehensive review on plastic waste utilization in concrete, paver blocks and bituminous roads, Journal of Cleaner Production, vol. 275, p. 123986, 2020.
[Online]. Available: https://www.researchgate.net/publication/389040145_A_Comprehensive_Review_of_Studies_on_Plastic_Waste_Utilisation_in_Road_and_Concrete_Infrastructure.

[5] M. S. Fofana, J. O. Obre Sery, E. Emeruwa, and A. J. Yomanfo, Influence of plastic and coconut shell (cocos nucifera l.) on the physico-mechanical properties of the 8/6 composite rafter, Open Journal of Composite Materials, vol. 13, pp. 57 68, 2023.

[6] O. Obiukwu, S. Ezenwa, and A. Okoye, Study on the properties of coconut shell powder reinforced high-density polyethylene composite.
[Online] Available: https://www.researchgate.net/publication/335244032_Study_on_the_Properties_of_Coconut_Shell_Powder_Reinforced_High-Density_Polyethylene_Composite, 2016.

[7] G. H. Manjunatha Chary and K. Sabeel Ahmed, Experimental characterization of coconut shell particle reinforced epoxy composites, Journal of Materials and Environmental Sciences, vol. 8, no. 5, pp. 1661 1667, 2017.
[Online] Available: https://www.researchgate.net/publication/315803387_Experimental_characterization_of_coconut_shell_particle_reinforced_epoxy_composites_Manjunatha_Chary_G_H_Ahmed_K_S_J_Mater_Environ_Sci_8_5_2017_1661-1667.

[8] D. O. Bichang'a, A. N. Wanjiru, D. Wanjala, and S. Ouma, Comparative property investigation of raw and treated coconut shell biomass for potential polymer composite application, Heliyon, vol. 10, p. e40704, 2024.
[Online]. Available: https://www.sciencedirect.com/science/article/pii/S2405844024167357.

[9] O. Faruk, A. K. Bledzki, H.-P. Fink, and M. Sain, Biocomposites reinforced with natural fibers: 2000 2010, Progress in Polymer Science, vol. 37, no. 11, pp. 1552 1596, 2012.

[10] N. Dorbane, B. Guendouzi, and A. Mezrig, Valorisation des déchets plastiques, une opportunité pour le développement local durable. Référence empirique la wilaya de tiziouzou, Magallat Al-Iqtisadiat Al-Chamaliyat Li Ifriqia, vol. 17, no. 1, pp. 629 646, 2021.
[Online]. Available: https://asjp.cerist.dz/en/article/146374.

[11] R. Menad and O. Bouras, Élaboration d'une nouvelle génération de pavés à base de déchets plastiques et de sable, Mémoire de Master, Université Blida 1, 2021. [Online]. Available: http://di.univ-blida.dz: 8080/jspui/handle/12 3456789/13077.

[12] A. Kumi-Larbi Jnr, L. Mohammed, T. A. Tag bor, S. K. Tulashie, and C. Cheeseman, Re cycling waste plastics into plastic-bonded sand interlocking blocks for wall construction in de veloping countries, Sustainability, vol. 15, p. 16602, 2023.

[13] S. Benimam, F. Debieb, M. Bentchikou, and M. Guendouz, Valorisation et recyclage des déchets plastiques dans le béton, in Communication de Conférence, 2014.

[14] S. O. Anuchi, K. L. Sedransk Campbell, and J. P. Hallett, E ective pretreatment of lignin rich coconut wastes using a low-cost ionic liq uid, Scienti c Reports, vol. 12, p. 6108, 2022.