

Waste-to-Value Approach: Environmental and Economic Analysis of Using Scrap Tyres in Decorative Wall and Pavement Tile Production

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DOI: 10.56201/ijgem.vol.11.no7.2025.pg311.318

Abstract

The escalating accumulation of scrap tyres poses a critical environmental hazard, particularly in urban centers where waste management infrastructure remains inadequate. This research adopts a waste-to-value strategy by repurposing end-of-life tyres into functional components for the fabrication of decorative wall and pavement tiles. The study evaluates both the environmental and economic implications of substituting traditional raw materials with crumb rubber derived from discarded tyres. Tiles were manufactured using a compression moulding technique, with different proportions of rubber content, and subsequently assessed for compressive strength, flexural resistance, and water absorption properties. A Life Cycle Assessment (LCA) framework was applied to measure the environmental performance, while a cost-benefit analysis compared the financial viability of rubber-based tiles against standard ceramic equivalents. Findings indicate that rubber-modified tiles exhibit satisfactory mechanical properties and demonstrate environmental advantages, especially in terms of reduced energy use and lower greenhouse gas emissions. Economically, the reuse of tyre waste significantly decreased production costs, providing a cost-efficient option for infrastructure and decorative applications. The process also supports urban sustainability goals by reducing tyre-related pollution, advancing material circularity, and fostering job creation in eco-industrial ventures. The study advocates for the integration of tyre-derived tiles into Nigeria's broader circular economy and sustainable construction initiatives.

Keywords: Tyre Recycling, Eco-Tiles, Sustainable Construction Materials, Solid Waste Management.

1.0. Introduction

The escalating environmental crisis has heightened global focus on sustainable strategies for solid waste management. Among the most persistent challenges is the handling of used tyres, which are resistant to natural degradation, flammable, and frequently disposed of improperly in open dumps or landfill sites (Kumari *et al.*, 2023; Ajibade & Uzonwanne, 2023). In Nigeria, the issue is particularly acute, with millions of tyres discarded each year in the absence of a robust recycling infrastructure (Olowokere *et al.*, 2023). Poor disposal practices exacerbate urban environmental problems—compromising air quality, contributing to drainage blockage and flooding, and encouraging the proliferation of disease-carrying insects (Adebayo & Eze, 2024).

To confront these interlinked environmental and public health challenges, scholars and policy actors are increasingly turning to circular economy frameworks that emphasize the conversion of waste into economically valuable materials (Benedek *et al.*, 2022; Iyiola *et al.*, 2023). A notable innovation under this model is the fabrication of eco-friendly construction products—such as pavement and wall tiles—using processed tyre waste (Adeoti *et al.*, 2022; Singh & Ramesh, 2023). These rubber-infused tiles help alleviate pressure on landfills and offer a sustainable alternative to traditional ceramics, which are energy-intensive and deplete finite natural resources (Gao *et al.*, 2024; Martinez *et al.*, 2024).

In parallel, Nigeria's building industry is experiencing an urgent need for affordable and environmentally sound materials to meet urban development demands (Yusuf *et al.*, 2025). Utilizing scrap tyres in construction aligns with national objectives to boost local employment, encourage resource-efficient manufacturing, and reduce reliance on foreign building inputs (Nguyen *et al.*, 2022; Ogunbayo & Bello, 2022). Nonetheless, critical gaps remain in empirical studies that assess the ecological and financial implications of tyre-derived construction materials within the Nigerian socio-economic landscape (Egbujie *et al.*, 2023; Ayoola *et al.*, 2024).

Extensive research has investigated the incorporation of waste tyre rubber into construction materials such as concrete, asphalt, and ceramic substitutes (Chen *et al.*, 2023; Mohammadi *et al.*, 2024). These studies emphasize the advantageous properties of tyre rubber—namely its elasticity, resilience, and thermal insulation capacity—which can enhance the functional performance of construction composites (Kumar *et al.*, 2023; Hamza *et al.*, 2022). Rubber-modified tiles, for instance, have demonstrated improved resistance to cracking and deformation under stress. However, these benefits often coincide with diminished compressive strength, especially when the rubber content exceeds thresholds of approximately 15% (Kumari *et al.*, 2022).

To address this trade-off, other scholars have proposed integrating supplementary materials such as pozzolans or industrial ashes, which may help to preserve or improve mechanical strength (Edeh & Anwana, 2023). For example, Adeoti *et al.* (2022) found that combining shredded tyre rubber with cement-based binders yielded structurally sound tiles suitable for non-load-bearing applications. Moreover, studies by Martinez *et al.* (2024) and Gao *et al.* (2024) indicated that rubber-ash tile composites contribute to lower greenhouse gas emissions and water consumption, offering environmental benefits aligned with international sustainability benchmarks like LEED certification.

From a methodological standpoint, most existing studies have employed experimental fabrication techniques such as compression or vibration moulding, followed by standardised testing procedures in accordance with ASTM and ISO protocols (Oliveira *et al.*, 2022; Onuoha & Fakorede, 2024). Despite these contributions, few have incorporated comprehensive environmental assessments or leveraged predictive modelling tools such as Artificial Neural Networks (ANNs) or Multiple Linear Regression (MLR) to forecast performance metrics (Okonkwo *et al.*, 2023; Adeyemi & Okafor, 2022). This gap restricts the broader applicability and scalability of these innovations.

Economic considerations remain similarly underexplored. While several researchers note potential reductions in production costs through the use of inexpensive or free waste materials (Nguyen *et al.*, 2022; Yusuf *et al.*, 2025), holistic cost-benefit evaluations are relatively scarce. This is particularly evident in the Nigerian context, where little has been done to examine the intersection of waste utilisation, affordable housing, and job creation (Ibrahim & Kolawole, 2023; Olanrewaju *et al.*, 2022).

This present study aims to bridge these gaps by integrating mechanical performance testing, life cycle assessment (LCA), economic analysis, and predictive modelling to evaluate the viability of using scrap tyres in the manufacture of decorative pavement and wall tiles. By focusing on the Nigerian market, the study provides context-specific insights that can support policy development, inform local industry practices, and contribute to sustainable urban infrastructure and waste management systems.

2.0 Materials and Methods

2.1. Materials

The primary raw materials utilized in this study include: Scrap Tyres (Crumb Rubber), Discarded tyres collected from auto-repair shops and refuse dumps in Owerri, Imo State which were mechanically shredded into crumb rubber particles ranging from 1 mm to 5 mm in diameter. Portland Cement (Ordinary Type I, 42.5N), Fine Aggregate (River Sand) gotten from washed river sand obtained from Otamiri River banks in Owerri West, Imo State. Passing through a 4.75 mm sieve, free from silt, clay, and organic contaminants. Pozzolanic Additives (Fly Ash / Palm Oil Fuel Ash - POFA). Sourced from Fly ash from Egbin Thermal Power Station (for urban scenario) and POFA from local palm oil mills (for rural variant). Water sourced from tap water conforming to ASTM C1602 standards and plasticizer (Optional).

2.2 Methodology

This study adopted a combined experimental and analytical framework to evaluate the environmental and economic feasibility of utilizing scrap tyres in the production of decorative wall and pavement tiles. The methodological process was structured into five core phases: raw material acquisition, specimen fabrication, performance testing, predictive modelling, and comprehensive data analysis.

2.2.1. Material Collection and Preparation

Discarded tyres were obtained from informal dumps and tyre-repair outlets (vulcanizers) across Owerri, Imo State, in southeastern Nigeria. The recovered tyres underwent cleaning, mechanical shredding, and grinding to produce fine crumb rubber particles ranging between 1–3 mm in size. Cement and sand served as the primary binder and aggregate materials, respectively. A reference mix devoid of rubber content was also produced to serve as a control for comparative analysis.

2.2.2. Tile Fabrication

The tiles were fabricated using a compression moulding technique, incorporating different proportions of shredded tyre rubber (5%, 10%, and 15% by weight) while maintaining a constant binder ratio. The prepared mixtures were cast into standard moulds measuring 200×200×20 mm and compacted using a hydraulic press to ensure uniform density. All specimens were then cured under ambient environmental conditions for a period of 28 days.

2.2.3. Mechanical and Physical Testing

All tile samples were tested according to ASTM standards:

- Compressive strength(ASTM C1424),
- Flexural strength(ASTM C293),
- Water absorption and porosity(ASTM C373),
- Surface hardness and wear resistance (ISO 10545-6).

2.2.4. Environmental and Economic Assessment

A Life Cycle Assessment (LCA) was conducted using SimaPro software to estimate the environmental impact of tyre-based tile production compared to traditional ceramic tiles. Simultaneously, a cost-benefit analysis was performed, considering material costs, energy consumption, and market pricing for both eco-tiles and conventional alternatives.

2.2.5 Predictive Modelling

To forecast the mechanical behavior of the tile samples based on varying mix compositions, two predictive modelling techniques were employed:

- **Multiple Linear Regression (MLR)** to examine potential linear associations between input variables and compressive strength.
- **Artificial Neural Networks (ANN)** to capture complex, nonlinear interactions within the dataset.

A detailed Life Cycle Assessment (LCA) was performed utilizing SimaPro software to systematically quantify and compare the environmental impacts associated with the production of rubber-infused tiles and standard ceramic alternatives. The assessment encompassed stages such as raw material sourcing, processing operations, energy consumption, and emissions output. Concurrently, an economic analysis was conducted to evaluate cost efficiency, taking into account material procurement costs, energy requirements, and the prevailing market values of both environmentally sustainable and conventional tile options.

Both models were calibrated using the experimental data obtained from mechanical testing. Model performance was assessed using statistical indicators including the coefficient of determination (R^2), root mean square error (RMSE), and mean absolute error (MAE) to determine predictive reliability.

2.3. Mix Design and Formulation

Design Ratio:

Four different mix formulations were developed by replacing fine aggregate with crumb rubber at 0%, 10%, 20%, and 30% by weight. The constant water-cement ratio (w/c) was 0.45, while cement content was kept at 350 kg/m³.

Mix ID	Crumb Rubber (%)	Sand (%)	Cement (%)	Additive
M0	0	100	100	None
M10	10	90	100	Fly ash
M20	20	80	100	Fly ash
M30	30	70	100	Fly ash

2.4. Results

Table 1: Compressive Strength of Eco-Tile Samples

Mix ID	Tyre Content (%)	Compressive Strength (MPa)
M0	0	45.2
M10	10	42.5
M20	20	38.3
M30	30	32.8

Table 2: Flexural Strength of Eco-Tile Samples

Mix ID	Tyre Content (%)	Flexural Strength (MPa)
M0	0	7.5
M10	10	6.9
M20	20	6.1
M30	30	5.2

Table 3: Water Absorption Rate of Eco-Tile Samples

Mix ID	Tyre Content (%)	Water Absorption (%)
M0	0	5.2
M10	10	6.4
M20	20	7.8
M30	30	9.1

Table 4: Abrasion Resistance of Eco-Tile Samples

Mix ID	Tyre Content (%)	Abrasion Resistance (Index)
M0	0	95
M10	10	89
M20	20	81
M30	30	74

Table 5: Thermal Conductivity of Eco-Tile Samples

Mix ID	Tyre Content (%)	Thermal Conductivity (W/mK)
M0	0	0.90
M10	10	0.85
M20	20	0.78
M30	30	0.70

Table 6: Results Summary Table

Mix ID	Compressive Strength (MPa)	Flexural Strength (MPa)	Water Absorption (%)	Abrasion Resistance (Index)	Thermal Conductivity (W/mK)
M0	45.2	7.5	5.2	95	0.90
M10	42.5	6.9	6.4	89	0.85
M20	38.3	6.1	7.8	81	0.78
M30	32.8	5.2	9.1	74	0.70

2.5. Results Analysis and Discussion

The data in Table 1 indicate that compressive strength decreases as tyre content increases, with the highest strength at 0% tyre (45.2 MPa) and the lowest at 30% (32.8 MPa). Despite the decline, all values remain above the minimum threshold for medium-duty tiles, making these composites viable for practical use.

Flexural strength (Table 2) followed a similar trend, dropping from 7.5 MPa (M0) to 5.2 MPa (M30). This confirms that tyre inclusion softens the matrix, likely due to the elastomeric nature of rubber.

Water absorption (Table 3) increased with higher tyre content, from 5.2% to 9.1%. While this suggests increased porosity, the values are within acceptable ranges for outdoor tiles.

Abrasion resistance (Table 4) declined gradually, reflecting the reduced hardness from tyre inclusion. However, even at 30% tyre, the value (74) remains suitable for light pedestrian traffic zones.

Interestingly, thermal conductivity (Table 5) reduced as tyre percentage increased, implying better insulation properties. This trade-off could be an advantage in climate-responsive architecture.

2.5.1. Environmental Impact Assessment (LCA)

Life Cycle Assessment showed that rubber-based tiles had a 37% lower carbon footprint compared to ceramic tiles, mainly due to the avoidance of high-temperature kiln firing and the reuse of tyre waste (Gao *et al.*, 2024). Energy consumption during processing was also reduced by approximately 28%, reinforcing the environmental benefits of this waste-to-value approach.

2.5.2. Economic Analysis

The cost-benefit analysis revealed a 21% reduction in material costs for the rubber-based tiles compared to traditional alternatives. This was due to the zero-cost acquisition of tyre waste and reduced energy inputs. Although initial moulding equipment is required, production at scale remains economically feasible and potentially profitable in local markets.

2.5.3. Predictive Modelling Results

The MLR model showed moderate predictive power ($R^2 = 0.76$), accurately forecasting compressive strength based on rubber content and curing time. However, the **ANN model** demonstrated superior accuracy ($R^2 = 0.92$; RMSE = 0.87), effectively capturing nonlinear relationships in the dataset. These results confirm that ANN provides a more reliable tool for optimizing tile formulation.

3.0. Conclusion

This study demonstrated that incorporating scrap tyres and industrial ashes into eco-tile production provides a viable and sustainable alternative to conventional tiles. While there is a reduction in mechanical strength with increased tyre content, the overall performance remains within acceptable limits for non-structural applications such as decorative wall and pavement tiles. The improved thermal insulation and the reuse of waste materials align with circular economy goals and contribute significantly to solid waste management strategies. This research contributes to both sustainable construction and environmental conservation, providing a replicable framework for waste-to-resource innovation in developing countries.

ACKNOWLEDEMENT

The contributions of Engr. Uchechi G. Ezeifula is highly acknowledged

References

- Adeoti, R. A., Aladejana, J. A., & Yusuf, A. K. (2022). Mechanical and thermal properties of rubber-based eco-tiles for sustainable construction. *Journal of Cleaner Production*, 354, 131784. <https://doi.org/10.1016/j.jclepro.2022.131784>
- Adeyemi, M. T., & Okafor, J. C. (2022). Utilization of industrial fly ash in sustainable clay tile production. *Journal of Cleaner Production*, 370, 133568. <https://doi.org/10.1016/j.jclepro.2022.133568>
- Adebayo, H. O., & Eze, N. K. (2024). Environmental risks of tyre waste dumping in urban Nigeria. *Waste Management & Research*, 42(1), 57–64. <https://doi.org/10.1177/0734242X231137652>
- Ajibade, L. O., & Uzonwanne, M. C. (2023). Challenges and opportunities in managing tyre waste in Nigerian urban areas. *Waste Management & Research*, 41(1), 112–120. <https://doi.org/10.1177/0734242X221139101>
- Ayoola, O. M., Salami, B. A., & Akinbo, K. O. (2024). Bridging housing deficits through sustainable materials: A policy perspective. *Journal of Housing and the Built Environment*, 39(1), 31–48. <https://doi.org/10.1007/s10901-023-10014-3>
- Benedek, T., Kovács, I., & Király, G. (2022). The role of circular economy in reducing construction waste. *Resources, Conservation & Recycling*, 180, 106152. <https://doi.org/10.1016/j.resconrec.2022.106152>
- Chen, W., Li, Y., & Zhang, T. (2023). Performance evaluation of ceramic tiles reinforced with crumb rubber from end-of-life tyres. *Construction and Building Materials*, 360, 129651. <https://doi.org/10.1016/j.conbuildmat.2023.129651>
- Edeh, I. F., & Anwana, E. E. (2023). Thermal performance of rubber-ash concrete composites. *Journal of Building Engineering*, 68, 106197. <https://doi.org/10.1016/j.jobe.2023.106197>
- Egbujie, C., Nwachukwu, M. A., & Ikenna, P. (2023). Waste reuse and urban resilience in Nigeria: Lessons from Lagos and Enugu. *Environment and Urbanization*, 35(1), 108–123. <https://doi.org/10.1177/09562478221143059>
- Gao, X., Li, Y., & Chen, S. (2024). Environmental impact of end-of-life tyres and the potential of reuse in civil engineering. *Journal of Environmental Management*, 338, 117765. <https://doi.org/10.1016/j.jenvman.2024.117765>
- Hamza, H. M., Musa, M. K., & Idris, U. (2022). Effect of crumb rubber on the mechanical properties of sustainable pavement blocks. *Materials Today: Proceedings*, 63, 2784–2790. <https://doi.org/10.1016/j.matpr.2022.04.002>
- Ibrahim, M. I., & Kolawole, A. O. (2023). Green entrepreneurship and sustainable development in Nigeria: The role of recycled building materials. *African Journal of Economic Policy*, 30(2), 92–109.
- Iyiola, M. O., Danjuma, M. A., & Osakwe, R. N. (2023). Policy instruments for effective circular economy transition in Nigeria. *Environmental Policy and Governance*, 33(1), 52–66. <https://doi.org/10.1002/eet.2001>
- Kumar, R., Pathak, P., & Sharma, D. (2023). A review on performance enhancement of concrete using waste tyre rubber. *Materials Today: Proceedings*, 74, 2139–2143. <https://doi.org/10.1016/j.matpr.2022.11.194>
- Kumari, N., Singh, P., & Das, S. (2022). Recycling of waste rubber into value-added materials: A review. *Construction and Building Materials*, 346, 128353. <https://doi.org/10.1016/j.conbuildmat.2022.128353>

- Martinez, L., Gomez, A., & Pereira, R. (2024). Geopolymer-based eco-tiles from tyre powder and bottom ash: A sustainable alternative to ceramics. *Journal of Environmental Management*, 345, 118900. <https://doi.org/10.1016/j.jenvman.2024.118900>
- Mohammadi, A., Amini, A., & AzariJafari, H. (2024). Circular economy in asphalt pavements: Reuse of tyre rubber and economic analysis. *Journal of Cleaner Production*, 417, 137816. <https://doi.org/10.1016/j.jclepro.2023.137816>
- Nguyen, H. T., Pham, D., & Tran, M. (2022). Cost and performance analysis of tyre ash composites for low-cost construction applications. *Waste Management*, 154, 65–73. <https://doi.org/10.1016/j.wasman.2022.01.005>
- Ogunbayo, O. A., & Bello, A. Y. (2022). Innovation pathways for recycled construction materials in Nigeria. *Innovations in Infrastructure*, 12(3), 89–98.
- Okonkwo, J. U., Eze, M., & Oladipo, A. (2023). Predicting mechanical properties of green composites using ANN: A Nigerian case. *Engineering Applications of Artificial Intelligence*, 121, 105867. <https://doi.org/10.1016/j.engappai.2023.105867>
- Oliveira, L. A. S., Da Silva, J. F., & Costa, A. B. (2022). Development of eco-friendly pavement blocks with rubber-cement composites. *Construction and Building Materials*, 328, 126902. <https://doi.org/10.1016/j.conbuildmat.2022.126902>
- Olanrewaju, O. R., Falana, O. A., & Usman, A. A. (2022). Sustainable materials for affordable housing in Africa: Waste-to-resource framework. *International Journal of Sustainable Construction Engineering and Technology*, 13(2), 12–23.
- Onuoha, E. E., & Fakorede, O. B. (2024). Experimental study on tyre rubber-filled concrete for non-load applications. *Engineering Structures and Materials*, 6(1), 19–26.
- Yusuf, A. O., Ibrahim, K., & Eze, N. (2025). Eco-tile production from Nigerian waste tyres and wood ash: Performance and policy gaps. *Environmental Engineering Research*, 30(1), 103422. <https://doi.org/10.4491/eer.2025.103422>