

Review Paper on Eco-Friendly Roofing Tiles using Agro waste Material

Ranjeet S. Patil¹, Adnya Manjarekar²

¹ PG Student, Department of Civil Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India – 416118.

² Assistant Professor, Department of Civil Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India – 416118.

DOI: 10.5281/zenodo.20646421

ABSTRACT

The construction sector faces mounting pressure to reduce its environmental footprint while addressing housing demands, particularly in developing economies. Simultaneously, agricultural waste disposal through open burning and landfilling contributes significantly to greenhouse gas emissions and environmental degradation. This review paper examines the emerging paradigm of eco-friendly roofing tiles manufactured using agrowaste materials as a synergistic solution to both challenges. Through systematic analysis of literature published between 2017 and 2024, this paper synthesizes current knowledge on various agricultural residues, including rice husk ash, sugarcane bagasse, coconut coir, com cob, and ceramic sludge employed in roofing tile production. The review evaluates the mechanical properties, durability, thermal performance, and economic viability of agrowaste-based tiles. Key findings indicate that optimal replacement levels of 10-20% for cement or clay matrices maintain or enhance specific performance parameters while reducing weight by up to 4.9% and achieving temperature reductions of 4.4°C compared to conventional tiles. Water absorption values consistently fall within ASTM standards, and durability against chemical attacks improves with combined waste incorporation. However, challenges persist regarding standardization, long-term performance validation, and market acceptance. This review identifies research gaps and proposes future directions for advancing agrowaste-based roofing technologies toward commercial viability.

Keywords: - Agricultural waste, sustainable construction, roofing tiles, rice husk ash, circular economy, green building material

1. INTRODUCTION

The construction industry stands as one of the largest contributors to global greenhouse gas emissions, with cement production alone accounting for approximately 8% of global CO₂ emissions. The extraction, transportation, and processing of raw materials for building components further exacerbate environmental degradation. Concurrently, agricultural

activities generate vast quantities of waste residues, rice husks, sugarcane bagasse, coconut husks, corn cobs, and numerous other byproducts that require disposal. Traditional disposal methods, particularly open-field burning and landfilling, release significant greenhouse gases and particulate matter into the atmosphere [1].

This convergence of environmental challenges presents an opportunity for innovative solutions that address both problems simultaneously. Roofing tiles, essential components of building envelopes, represent a promising application for agrowaste incorporation due to their high production volumes, established manufacturing processes, and potential for material substitution without compromising functional requirements [2].

The concept of ecological roofing tiles has gained traction over the past decade, with researchers exploring various waste streams, including Tetra-Pak packaging, PET bottles, and diverse agricultural residues. However, a comprehensive synthesis of knowledge specifically focused on agrowaste-based roofing tiles remains lacking. This review paper aims to fill this gap by systematically examining the current state of research on eco-friendly roofing tiles manufactured using agricultural waste materials [3].

The objectives of this review are threefold: (1) to identify and categorize the types of agricultural wastes successfully employed in roofing tile production, (2) to evaluate the mechanical, physical, and durability properties of agrowaste-based tiles against established standards, and (3) to assess the environmental and economic implications of adopting these materials in construction practice [4].

2. AGRICULTURAL WASTES IN ROOFING TILE PRODUCTION

2.1 Classification of Agrowaste Materials

Agricultural wastes suitable for roofing tile applications can be broadly categorized based on their origin and processing requirements. Rice husk, one of the most extensively studied materials, is generated during rice

milling operations and possesses high silica content that contributes to pozzolanic activity when burned under controlled conditions. Sugarcane bagasse, the fibrous residue after juice extraction, similarly exhibits pozzolanic properties when incinerated to produce ash [5].

Coconut coir fiber, derived from coconut husks, offers reinforcement potential due to its tensile strength and durability. Studies have demonstrated that coir fiber can effectively replace conventional sisal fiber in concrete roofing tiles while maintaining acceptable mechanical performance. Corn cob, another abundant agricultural residue, has been investigated as a partial replacement for river sand in tile manufacturing. Ceramic sludge, while not strictly agricultural, often appears in conjunction with agrowaste research as an industrial byproduct that complements agricultural residues in composite formulations [6,7].

2.2 Geographic Availability and Regional Considerations

The availability of specific agrowaste materials varies significantly across geographic regions, influencing the practicality of their adoption. Rice-producing regions of Asia, including India, China, and Southeast Asian nations, generate substantial quantities of rice husk requiring disposal. Sugarcane-growing areas in Brazil, India, and parts of Africa produce corresponding bagasse waste streams. Coconut-producing coastal regions offer coir fiber resources, while corn-growing areas provide corn cob residues [8].

This geographic distribution suggests that regionally-optimized formulations may prove most sustainable, minimizing transportation emissions while utilizing locally available waste streams. The concept of "waste proximity" aligns with circular economy principles and reduces the carbon footprint associated with material transportation [5].

3. MANUFACTURING PROCESSES

3.1 Preparation of Agrowaste Material

The processing of agricultural wastes for roofing tile applications typically involves several preparatory steps. For rice husk and sugarcane bagasse, controlled incineration produces ash with optimized pozzolanic properties. Open-air burning, while common in developing regions, may produce inconsistent quality and environmental emissions; therefore, controlled furnace burning at temperatures between 600-800°C is recommended to achieve amorphous silica phases that contribute to cementitious reactions [9].

Fiber-based materials such as coir require cleaning, drying, and sometimes chemical treatment to enhance bonding with cementitious matrices and reduce water absorption that could compromise long-term durability. Particle size reduction through grinding or milling ensures uniform distribution within the tile matrix [10].

3.2 Mix Designs and Proportion

Research has explored various replacement levels for conventional materials. In cement mortar roof tiles, rice husk ash (RHA) and sugarcane bagasse ash have been investigated at replacement levels of 10%, 15%, and 20% of ordinary Portland cement by weight. Results indicate that moderate replacement levels maintain acceptable compressive and transverse strength while reducing material costs. In fired clay tile production, combinations of RHA and ceramic sludge have demonstrated promising results. A study replacing clay with 10% RHA and 10% ceramic sludge achieved optimal performance, with a transverse breaking load of 1519 N representing a 6.5% improvement over conventional tiles. Higher replacement levels (20% ceramic sludge) showed reduced strength (1427 N), suggesting optimal thresholds for combined waste incorporation. Concrete roofing tiles incorporating coir fiber have been formulated by replacing conventional sisal fiber with coir while substituting plaster sand with clayey soil. Five different mix designs were evaluated, with results indicating that 100% coir fiber replacement can achieve commercially viable products, though with slightly reduced strength compared to sisal-reinforced controls [11].

3.3 Production Techniques

Agrowaste-based roofing tiles can be manufactured using modified versions of conventional production processes. For cementitious tiles, vibration casting or pressing methods similar to standard concrete tile production apply, with adjustments for the altered rheology of waste-containing mixtures. Fired clay tiles incorporating RHA and ceramic sludge can be processed through conventional extrusion and firing operations, though firing temperatures and durations may require optimization based on waste material characteristics [12].

4. PERFORMANCE EVALUATION

4.1 Mechanical Properties

Transverse Breaking Strength: Transverse strength represents a critical performance parameter for roofing tiles, indicating resistance to bending loads from wind, snow, or installation loads. Studies report transverse breaking loads ranging from 1427 N to 1519 N for tiles incorporating 10% RHA and varying ceramic sludge content.

These values generally meet or exceed minimum requirements specified in relevant standards, including ASTM C1492 and IS 1237-2012 [15].

The improvement in strength observed with combined waste incorporation (10% RHA + 10% CS) suggests synergistic effects where the pozzolanic activity of RHA complements the filler effect of ceramic sludge. This finding aligns with broader literature on supplementary cementitious materials, where combinations often outperform single additives [13].

Flexural Strength: Flexural strength testing at 28 days for coir fiber-reinforced concrete tiles demonstrated that 100% coir fiber replacement produces commercially viable products, though strength values remain below those achieved with sisal fiber reinforcement. This trade-off between sustainability and mechanical performance requires careful consideration for specific applications.

Compressive Strength: For cementitious tiles, compressive strength generally decreases with increasing agrowaste replacement beyond optimal levels. However, at 10-15% replacement with RHA or bagasse ash, compressive strength comparable to control mixes has been reported. The pozzolanic reaction between amorphous silica in RHA and calcium hydroxide from cement hydration contributes to strength development over time.

4.2 Physical Properties

Water Absorption: Water absorption directly influences durability, freeze-thaw resistance, and potential for biological growth. Tiles incorporating 10% RHA and 10% ceramic sludge exhibited water absorption of 15.25%, while coir fiber-reinforced concrete tiles maintained absorption values within ASTM C1492 acceptable limits. Higher absorption in waste-containing tiles reflects increased porosity, which may be beneficial for certain applications, such as thermal regulation, but requires careful management in freeze-prone climates.

Density and Weight Reduction: A significant advantage of agrowaste incorporation is weight reduction, offering benefits for structural loading and installation. Tiles with 10% RHA and 10% ceramic sludge achieved 4.9% dry mass reduction compared to conventional clay tiles. This weight reduction translates to lower transportation costs and reduced structural requirements for roof framing.

Porosity and Microstructure: Scanning electron microscopy (SEM) analysis confirms increased porosity in tiles containing RHA and ceramic sludge. This microstructural characteristic contributes to both thermal performance and water absorption behavior. The pore structure distribution influences capillary action and moisture transport, requiring optimization for specific climatic conditions.

4.3 Durability Characteristics

Chemical Resistance: Durability against acid and alkaline attacks improves with combined waste incorporation. Studies report that increasing combined waste content from 10% to 30% reduced weight gain from acid attack from 3.5% to 3.0%, and from alkaline attack from 2.2% to 1.6%. This enhanced chemical resistance suggests improved long-term performance in aggressive environments.

Freeze-Thaw Resistance: While specific freeze-thaw data for agrowaste tiles remains limited, the relationship between water absorption and freeze-thaw durability suggests that tiles with higher porosity may require additional consideration in cold climates. Surface treatments or optimized formulations may address this concern.

Long-Term Performance: Longitudinal studies tracking agrowaste tile performance over extended periods are lacking in the current literature. Most research reports 28-day or short-term accelerated testing, leaving questions about 10-20-year performance unanswered. This knowledge gap represents a significant barrier to widespread adoption.

4.4 Thermal Performance

Temperature regulation represents an emerging advantage of agrowaste-based tiles. Tiles manufactured with 10% RHA and 10% ceramic sludge achieved 4.4°C temperature reduction compared to conventional clay tiles under identical exposure conditions. This thermal benefit, attributed to increased porosity and lower thermal conductivity, contributes to building energy efficiency and occupant comfort. The thermal performance improvement aligns with findings from living roof systems, where organic matter and porous substrates enhance insulation. For low-income housing in tropical climates, this temperature reduction could significantly reduce cooling energy requirements and improve indoor comfort [16].

4.5 Environmental Impact Assessment

Run-off Water Quality: An important environmental consideration for roofing materials is the quality of water harvested from roof surfaces. Research evaluating run-off from RHA and ceramic sludge tiles found pH values and total solid concentrations within recommended ranges for agricultural water use. This finding supports rainwater harvesting applications and confirms that agrowaste tiles do not leach harmful substances under normal exposure.

Carbon Footprint: The environmental benefits of agrowaste tiles derive from two mechanisms: avoided

emissions from waste disposal (particularly open burning) and reduced cement or clay consumption. Lifecycle assessment studies specific to agrowaste tiles remain limited, but broader research on agricultural waste in construction suggests significant carbon reduction potential.

Circular Economy Contribution: By valorizing agricultural residues that would otherwise require disposal, agrowaste tiles contribute to circular economy objectives. This approach aligns with multiple Sustainable Development Goals (SDGs), including responsible consumption and production (SDG 12), climate action (SDG 13), and sustainable cities and communities (SDG 11).

5. ECONOMIC ANALYSIS

5.1 Cost Comparison with Conventional Tiles

Economic viability represents a critical factor for adoption, particularly in affordable housing applications. Research comparing Tetra-Pak-based tiles with conventional options found that while ecological tiles offer environmental benefits, their price remained high relative to market alternatives. However, this finding may not apply universally across different agrowaste types and geographic contexts. For agricultural wastes with negative disposal costs (where farmers pay for removal), raw material costs approach zero, potentially enabling significant cost reductions. Transportation and processing costs remain, but economies of scale could reduce these with widespread adoption [17].

5.2 Scalability and Market Considerations

Scaling agrowaste tile production from laboratory to industrial scale presents multiple challenges. Consistent waste material quality, reliable supply chains, and modified production equipment requirements must be addressed. Studies utilizing industrial-scale production facilities have demonstrated the feasibility of RHA and ceramic sludge tiles, suggesting that scalability is achievable with appropriate technology transfer. Market acceptance depends on demonstrated performance, certification under relevant standards, and cost competitiveness. Early adoption in farm buildings, green building projects, and affordable housing programs may provide initial market footholds [16].

6. CHALLENGES AND LIMITATIONS

6.1 Technical Challenges

Material Variability: Agricultural waste composition varies with crop variety, growing conditions, harvesting methods, and processing techniques. This variability complicates quality control and may produce inconsistent tile properties. Standardized processing protocols and blending strategies can mitigate variability but add complexity.

Optimal Formulation Determination: The wide range of potential agrowaste types, replacement levels, and processing conditions creates a vast experimental space. Systematic optimization studies are needed to identify optimal formulations for specific waste types and applications.

Long-term Durability Validation: The absence of long-term field performance data limits confidence in agrowaste tiles for permanent construction. Accelerated aging studies and monitored field installations are needed to establish service life predictions.

Current building standards and codes generally lack provisions for agrowaste-based materials, creating regulatory barriers to adoption. Research demonstrating compliance with existing standards (e.g., ASTM C1492, IS 1237-2012) provides a pathway for certification, but dedicated standards for ecological tiles would facilitate broader acceptance.

6.2 Social and Cultural Barriers

Construction industry conservatism, builder unfamiliarity with alternative materials, and homeowner preferences for traditional products represent social barriers to adoption. Demonstration projects, technical guidance documents, and awareness campaigns can address these challenges but require coordinated effort from researchers, industry associations, and government agencies.

7. CONCLUSION

This review has synthesized current knowledge on eco-friendly roofing tiles manufactured using agricultural waste materials, revealing significant progress and persistent challenges. The evidence demonstrates that rice husk ash, sugarcane bagasse, coconut coir, corn cob, and ceramic sludge can be successfully incorporated into roofing tile formulations at optimal replacement levels of 10-20%, maintaining or improving specific performance characteristics while reducing environmental impacts. Key findings include: (1) transverse breaking strengths meeting or exceeding standard requirements, (2) water absorption within acceptable limits, (3) weight reductions of approximately 5% contributing to material efficiency, (4) thermal performance

improvements achieving 4.4°C temperature reduction, and (5) enhanced durability against chemical attacks with combined waste incorporation. The dual environmental benefit, reducing both construction material impacts and agricultural waste disposal problems, positions agrowaste roofing tiles as a promising technology for sustainable development. However, realizing this potential requires addressing challenges related to material variability, long-term performance validation, standardization, and market acceptance. Future research should focus on underutilized waste streams, predictive modeling for formulation optimization, comprehensive lifecycle assessment, and long-term performance monitoring. With continued research and development, agrowaste-based roofing tiles can contribute meaningfully to sustainable construction practices while supporting circular economy objectives and reducing the environmental footprint of the building sector.

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