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Development and Performance Evaluation of Eco-Friendly Bricks Using Fly Ash, Coconut Shell, and Coconut Fiber- A Review

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Abstract- The construction industry is one of the major contributors to environmental degradation due to excessive consumption of natural resources such as clay, sand, and limestone, along with high carbon dioxide emissions from cement manufacturing and brick kiln operations. Conventional fired clay bricks require significant amounts of fertile soil and fuel, leading to depletion of agricultural land and emission of greenhouse gases. In recent years, the utilization of industrial and agricultural waste materials has emerged as a sustainable solution for manufacturing eco-friendly building bricks. Among these waste materials, fly ash, a by-product of thermal power plants, has gained significant attention due to its pozzolanic nature and availability in large quantities. Similarly, coconut shell and coconut fiber, which are agricultural residues, possess favorable properties such as low density, good toughness, and thermal insulation potential. This review paper presents a comprehensive study of the development and performance evaluation of eco-friendly bricks and blocks incorporating fly ash, coconut shell, and coconut fiber. A detailed literature survey of 16 previous research studies has been conducted to analyze the influence of these materials on the mechanical properties (compressive strength, tensile strength, flexural strength), physical properties (density, water absorption, porosity), durability behavior (thermal resistance, shrinkage, efflorescence), and sustainability aspects (cost-effectiveness, waste management, carbon reduction). The review indicates that fly ash contributes to strength development and reduced water absorption, coconut shell improves lightweight characteristics, and coconut fiber enhances crack resistance and ductility. However, challenges such as reduction in workability, increased water absorption due to fiber inclusion, and lack of standard mix design guidelines still exist. Based on the critical analysis, significant research gaps have been identified, particularly regarding optimization of mix proportions, performance evaluation under long-term durability conditions, and standardization of eco-friendly brick manufacturing procedures. The paper concludes that fly ash, coconut shell, and coconut fiber-based bricks can serve as promising sustainable alternatives for modern construction, but further experimental validation and field-scale studies are necessary for widespread adoption.

Keywords: Eco-Friendly Bricks, Fly Ash Bricks, Coconut Shell, Coconut Fiber, Sustainable Construction, Agricultural Waste, Industrial Waste, Lightweight Bricks, Green Building Materials.

I. INTRODUCTION

The construction industry plays a crucial role in the socio-economic development of any country, as it directly supports infrastructure growth, industrial development, and improvement in living standards. Over the past few decades, rapid urbanization, population growth, industrial expansion, and increasing demand for housing and public infrastructure have resulted in a massive rise in construction activities across the world. This continuous development has created a huge requirement for construction materials such as cement, steel, aggregates, sand, and masonry units. Among all building materials, bricks remain one of the most widely utilized construction components due to their easy availability, simple manufacturing process, affordability, durability, and suitability for various masonry applications such as load-bearing walls, partition walls, boundary walls, and architectural structures. Traditionally, burnt clay bricks have been extensively used for centuries because of their good compressive strength, moderate durability, and resistance to weathering.

However, the conventional method of manufacturing burnt clay bricks involves excavation of fertile topsoil, preparation of clay mix, molding, drying, and high-temperature firing in kilns. This firing process requires a significant amount of fuel, such as coal, wood, agricultural residues, or other fossil fuels, and releases large quantities of harmful gases into the atmosphere. The kiln burning process emits carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter, which contribute heavily to global warming, air pollution, and environmental degradation. Furthermore, large-scale clay soil excavation for brick production results in severe depletion of fertile agricultural land, loss of vegetation, and destruction of natural ecosystems. Therefore, despite the widespread use of clay bricks, their production process is increasingly being considered environmentally unsustainable and requires urgent replacement with greener alternatives. India is one of the leading brick manufacturing countries globally, producing billions of bricks annually to meet the demand of rapidly expanding cities, rural housing schemes, road development projects, and industrial construction. The Indian brick manufacturing sector mainly operates through small-scale and medium-scale kiln industries, many of which still follow traditional firing methods such as Bull's Trench Kilns (BTK) and clamp kilns. These kilns are recognized as major sources of air pollution in many regions, especially in the northern and central parts of India. The emissions from brick kilns contribute significantly to atmospheric particulate pollution, resulting in health hazards such as respiratory diseases, lung infections, and reduced air quality. In addition to air pollution, the brick industry consumes a large amount of water during molding and curing, and it also generates solid waste and dust pollution around kiln sites. Moreover, excessive removal of clay soil affects agricultural productivity by reducing the availability of fertile land for crop cultivation, which is a major concern in a developing country like India where agriculture remains a primary livelihood source. The continuous increase in brick demand and the limited availability of natural resources have forced researchers, engineers, and policymakers to focus on the development of sustainable building materials. Hence, there is an urgent requirement to shift from conventional clay bricks to alternative eco-friendly bricks that can reduce environmental pollution, conserve natural resources, and ensure sustainable infrastructure development without compromising construction quality.

In modern sustainable construction practices, the utilization of industrial and agricultural waste materials has emerged as an effective approach to minimize environmental impacts and improve resource efficiency. Industrial by-products such as fly ash, ground granulated blast furnace slag (GGBS), marble dust, silica fume, rice husk ash, red mud, and other waste powders are generated in large quantities by power plants, steel industries, cement industries, and manufacturing sectors. Improper disposal of such waste materials results in serious environmental problems such as land pollution, groundwater contamination, and air pollution due to fine dust particles. Among these wastes, fly ash is considered one of the most significant industrial residues, produced in enormous quantities by coal-based thermal power plants. Fly ash consists of fine particles rich in silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), making it a suitable pozzolanic material. Due to its cementitious behavior, fly ash can be effectively used as a partial replacement for cement and clay in bricks and blocks. Fly ash-based bricks are already being promoted in many countries because they do not require high-temperature kiln firing, thereby reducing energy consumption and greenhouse gas emissions. Fly ash bricks are also known for their improved compressive strength, better dimensional accuracy, smoother surface finish, reduced efflorescence, and lower water absorption compared to conventional clay bricks. Furthermore, the utilization of fly ash in construction reduces the burden of fly ash disposal and supports sustainable waste management, making it a valuable material for producing eco-friendly masonry units. In addition to industrial waste materials, agricultural waste residues also present a significant opportunity for developing sustainable construction materials. Coconut shell and coconut fiber are among the major agricultural wastes generated from coconut cultivation and processing industries. Coconut is widely grown in tropical and coastal regions such as India, Sri Lanka, Indonesia, Malaysia, and the Philippines. Coconut shells are produced in large volumes after extraction of coconut meat and water, and they are generally discarded as waste or burnt as fuel, leading to air pollution and resource wastage. Coconut shells possess favorable engineering properties such as hardness, toughness, low density, and good resistance to abrasion. Due to these characteristics, coconut shell has been explored as an alternative lightweight aggregate in concrete and masonry blocks. Similarly, coconut fiber (coir fiber), extracted from coconut husk, is a natural fiber with good tensile strength, high toughness, and excellent crack bridging ability. Coconut fiber has the ability to improve the ductility and tensile resistance of cementitious composites, making it an effective reinforcement material. Natural fibers like coconut fiber are biodegradable, renewable, and low-cost compared to synthetic fibers, and their use in construction contributes to environmentally friendly development. Coconut fiber reinforcement can reduce shrinkage cracks, enhance flexural strength, improve impact resistance, and increase energy absorption capacity of bricks and blocks. Therefore, the incorporation of coconut shell and coconut fiber in eco-friendly bricks not only provides a sustainable solution for waste disposal but also enhances certain mechanical and durability properties.

The combined integration of fly ash, coconut shell, and coconut fiber into brick manufacturing offers multiple advantages from both performance and sustainability perspectives. Fly ash can improve the binding properties of bricks due to its pozzolanic reaction, while coconut shell can reduce density and produce lightweight bricks with better thermal insulation. Coconut fiber can enhance toughness, reduce brittleness, and improve crack resistance, making bricks more durable under mechanical loading and shrinkage stresses. This combination can significantly reduce the dependency on natural clay soil and cement, which are non-renewable and high carbon footprint materials. Additionally, such eco-friendly bricks can reduce greenhouse gas emissions, decrease energy consumption, and support sustainable waste utilization. Lightweight bricks produced using coconut shell can also reduce dead load in structures, which is beneficial for seismic resistance and cost reduction in foundations. Furthermore, bricks with improved thermal insulation can reduce heat transfer in buildings, resulting in energy-efficient structures with lower cooling and heating requirements. Therefore, the development of eco-friendly bricks using these waste materials is highly beneficial for sustainable construction, resource conservation, and environmental protection.

However, despite the promising advantages of fly ash, coconut shell, and coconut fiber-based bricks, several technical and practical challenges remain. Many studies reported that the addition of coconut fiber reduces workability of cementitious mixes due to fiber entanglement and increased surface area, leading to poor compaction and void formation. Coconut shell and coconut fiber also have higher water absorption compared to conventional aggregates, which can increase porosity and reduce compressive strength if not properly treated or pre-soaked. Moreover, the absence of standardized mix design guidelines for combining fly ash, coconut shell, and coconut fiber makes it difficult to achieve consistent performance in brick manufacturing. Limited studies have been conducted on long-term durability performance, such as resistance against sulphate attack, acid exposure, freeze-thaw cycles, and weathering conditions. Additionally, microstructural studies explaining the bonding mechanism between fly ash binder matrix, coconut shell particles, and coconut fibers are still insufficient. These limitations indicate the need for further systematic research focusing on optimization of material proportions, curing conditions, fiber treatment techniques, and durability evaluation for large-scale practical implementation. Therefore, the present review paper aims to critically analyze existing research works related to fly ash bricks, coconut shell-based construction composites, and coconut fiber reinforced cementitious materials. This study focuses on evaluating their mechanical properties, physical characteristics, durability performance, and sustainability potential. A detailed review of 16 previous studies has been conducted to identify the major findings, limitations, and performance trends. Based on the literature analysis, this review highlights significant research gaps related to mix optimization, durability evaluation, standardization, and field-scale performance of eco-friendly bricks. The outcome of this review will provide a strong foundation for developing high-performance sustainable bricks using fly ash, coconut shell, and coconut fiber, and will contribute toward the promotion of eco-friendly materials for green building and sustainable infrastructure development.

II. LITERATURE REVIEW

A detailed review of sixteen previous research studies has been carried out in order to understand the current advancements, findings, and limitations associated with the development of eco-friendly bricks and construction materials using industrial and agricultural waste resources. The reviewed studies mainly concentrate on the utilization of fly ash as a partial replacement of cement and clay, the incorporation of coconut shell and coconut shell ash as lightweight aggregate or binder material, and the application of coconut fiber (coir fiber) as a natural reinforcing material to improve the toughness and crack resistance of bricks, blocks, and cementitious composites. These research works include experimental investigations, optimization-based studies, and review papers that evaluate the effect of these waste materials on the mechanical properties such as compressive strength, split tensile strength, and flexural strength, as well as physical characteristics including density, porosity, water absorption, and workability. Furthermore, several studies also highlight durability-related aspects such as thermal resistance, shrinkage behavior, and resistance against environmental exposure. Overall, the reviewed literature provides significant evidence that fly ash contributes to improved binding properties and long-term strength development due to pozzolanic reactions, coconut shell offers lightweight and thermal insulation benefits, and coconut fiber enhances ductility and crack-bridging capacity. However, the analysis of these sixteen studies also reveals critical limitations such as reduced workability, increased water absorption, and lack of standardized mix design procedures, which indicate the need for further research to optimize material proportions and evaluate long-term performance for practical construction applications.

Khale et al. (2025) investigated the performance of non-load-bearing precast concrete form blocks (PCFBs) incorporating fly ash and crushed glass as partial replacements for cement, and coconut fiber grains as partial replacements for fine aggregates. The study was conducted in the Philippines, where the rapid growth of the construction industry necessitates more efficient and sustainable building materials. Three experimental mixes—E.S.-1 (2.5% FA, 15% CG, 3% CFG), E.S.-2 (2.5% FA, 10% CG, 3% CFG), and E.S.-3 (2.5% FA, 5% CG, 3% CFG)—were compared against a control mix (1:3). The PCFBs were evaluated for compressive strength, water absorption, and weight classification after 7 and 14 days of curing. Results showed that E.S.-1 achieved the highest compressive strength of 2.65 MPa, although all samples exhibited a decline in strength by 14 days, likely due to inadequate curing conditions. Despite slightly higher production costs compared to the control, cost analysis suggested that PCFBs offer a competitive edge over market alternatives. Statistical analysis revealed no significant differences in compressive strength ($p > 0.05$) between the experimental and control samples, indicating the potential of these materials in sustainable construction. The authors recommended further research on mix designs and curing practices to enhance structural performance for broader construction applications.[1]

Kumar et al. (2024) investigated the development of an innovative eco-friendly concrete by partially substituting coir pith ash (CPA) for cement in coconut shell concrete, while also incorporating steel fibers and coconut fibers. The study explored CPA replacement levels ranging from 5% to 20% by cement weight, steel fibers at 0.25% to 1.0% by volume, and coconut fibers at 0.1% to 0.5% by volume. Their findings demonstrated that the inclusion of CPA significantly enhanced the mechanical properties of concrete, with compressive, flexural, and tensile strengths increasing by 10.36%, 8.75%, and 7.7%, respectively, at 28 days compared to control concrete. Furthermore, the combined use of coconut fibers and coconut shells improved the overall performance and durability of concrete, while promoting sustainable construction practices by reducing reliance on conventional materials and addressing solid waste disposal issues. This study highlights the potential of integrating agricultural by-products and natural fibers into concrete as a sustainable and high-performance alternative in the construction industry.[2]

Malayali et al. (2024) conducted an investigation on eco-friendly concrete reinforced with coconut waste chopped fiber (wCF) and hybridized with waste fly ash (wFA) and carbon nanotube (CNT) powder to improve mechanical performance and reduce shrinkage. The study aimed to enhance the compressive and flexural strengths of concrete while addressing sustainability by using agricultural and industrial waste materials. Concrete mixes were prepared with 5 wt% wCF, 10 wt% wFA, and varying CNT contents of 0%, 5%, 10%, and 15%, and were analyzed through X-ray diffraction, bulk density, mechanical testing, and water absorption studies. The results indicated that the optimum mix containing 5% wCF, 10% wFA, and 15% CNT exhibited the highest compressive strength (47 ± 1.8 MPa), flexural strength (4.9 ± 0.19 MPa), and low water absorption (2.8 ± 0.05%) after 28 days of curing. The study demonstrated that the synergistic use of coconut fiber, fly ash, and CNTs can produce high-performance, sustainable concrete with improved durability and reduced environmental impact, highlighting the potential of combining natural fibers and nanomaterials for eco-friendly construction applications.[3]

Lejano et al. (2024) performed an experimental investigation on coconut coir reinforced concrete by incorporating coconut shell ash (CSA) and coconut shell granules (CSG) as partial replacements for cement and sand, respectively. The study aimed to address environmental concerns associated with both agricultural waste disposal and cement-related carbon emissions. Fifteen concrete mixes were prepared with varying proportions of CSA and CSG (0–20%) and coconut coir (CC) fibers (0–2%), and were tested for workability, unit weight, compressive strength, and tensile strength. The findings revealed that higher concentrations of CSA, CSG, and CC reduced workability and produced lower unit weights due to the lower density and higher absorption of the agricultural wastes compared to conventional aggregates. Compressive and tensile strengths of the modified mixes were generally lower than conventional concrete; however, optimization using Response Surface Methodology (RSM) identified an optimal mix containing 2% CC, yielding compressive and tensile strengths of 23.046 MPa and 3.315 MPa, respectively. The study concluded that CSA-CSG coconut coir reinforced concrete is a feasible sustainable alternative for low-strength, non-structural applications such as patios and pathways, demonstrating the potential of agricultural by-products in eco-friendly concrete production.[4]

Tiwari et al. (2024) investigated the optimization of fly ash brick mixes incorporating marble dust, ground granulated blast-furnace slag (GGBS), and coconut shell ash (CSA) using a Design of Experiments (DOE) approach. The study aimed to determine the ideal proportions of these industrial and agricultural by-products to enhance compressive strength, durability, and reduce water absorption in bricks. Experimental results demonstrated that appropriate amounts of marble dust, GGBS, and CSA significantly improved mechanical performance while lowering water absorption, highlighting the synergistic effect of these materials. Statistical analysis enabled the identification of optimal mix proportions, providing a sustainable and economically viable alternative to conventional brick production. The study concluded that the integration of fly ash, marble dust, GGBS, and coconut shell ash in bricks promotes environmental sustainability, resource conservation, and development of durable building materials suitable for modern sustainable construction practices.[5]

Prakash et al. (2024) investigated the development of lightweight coconut shell concrete supplemented with Alccofine-1101 as a partial cement replacement to enhance sustainability and performance in construction. The study aimed to reduce reliance on natural aggregates and lower cement consumption, thereby addressing environmental concerns such as CO_2 emissions and resource depletion. Coconut shells were used as coarse aggregate, while Alccofine, consisting of ultrafine particles, was added at 5–15% to improve pozzolanic activity and hydration processes. The results showed that a 10% Alccofine replacement enhanced both workability and strength characteristics of the lightweight concrete. The study concluded that integrating coconut shell aggregates with Alccofine not only produces eco-friendly concrete with improved mechanical performance but also promotes sustainable construction practices by minimizing environmental impact and conserving natural resources.[6]

Priya and Padmanaban (2024) examined the use of coconut shell ash (CSA) as a partial replacement for cement in green concrete, addressing environmental concerns associated with cement production and the depletion of natural resources like river sand and gravel. Coconut shell ash, derived from the combustion of agricultural by-products, was substituted for cement in proportions ranging from 0% to 20% with 2.5% increments. The study found that a 12.5% CSA replacement yielded the maximum compressive strength, while durability tests confirmed satisfactory performance compared to conventional concrete. Specimens subjected to elevated temperatures (100 °C, 200 °C, and 300 °C) for one hour exhibited improved residual strength and reduced weight loss, indicating enhanced thermal resistance. The authors highlighted the potential of CSA as a sustainable, cost-effective, and environmentally friendly alternative to conventional cement, leveraging abundant agricultural waste to reduce greenhouse gas emissions and mitigate the carbon footprint of concrete production.[7]

Banogbanoga et al. (2024) explored the eco-friendly production of decorative concrete blocks by incorporating coal fly ash and coconut husk fiber as admixtures to cement and sand. The study applied a Mixture D-optimal design to optimize the block mixtures, varying coal fly ash from 2.33% to 28.33% and coconut husk fiber from 3% to 9% while keeping cement and sand constant at 10% and 58.67%, respectively. Decorative concrete blocks of 3,350 cm^3 were produced and cured for 28 days, after which they were tested for compressive strength, density, and water absorption capacity. Results indicated that the optimized blocks had a density of 1,153.27 kg/m^3, slightly lower than commercial blocks (1,165.39 kg/m^3), and a high-water absorption capacity of 24.79%. The compressive strength was recorded at 0.467 MPa, exceeding the commercial standard of 0.453 MPa, suggesting that the produced blocks could serve as a viable, cost-effective alternative. The study highlighted the potential of using industrial waste materials to create sustainable construction products, reducing solid waste generation and environmental pollution.[8]

Kiran et al. (2024) investigated the enhancement of mechanical properties in paver blocks by incorporating coconut fiber and construction and demolition waste (CDW) as a partial replacement for fine aggregates, employing multiple artificial intelligence (AI) techniques for optimization and prediction. The study considered factors such as cement content, natural fine aggregate, CDW, and coconut fiber, while evaluating mechanical properties of the paver blocks. Five AI methods—Response Surface Methodology (RSM), Support Vector Machine (SVM), Gradient Boosting (GB), Artificial Neural Networks (ANN), and Random Forest (RF)—were applied to forecast performance and optimize mix design. The results indicated that all AI models exhibited strong predictive capability, with GB and ANN showing superior performance compared to SVM and RF. This study demonstrated that integrating natural fibers with CDW in paver blocks, combined with AI-based optimization, can enhance mechanical properties while promoting sustainable construction practices and efficient utilization of waste materials.[9]

Martinelli et al. (2023) presented a comprehensive review on the use of coconut fibers in cementitious composites, highlighting their potential as sustainable alternatives to synthetic fibers in construction materials. The study discussed the production, characteristics, and treatment of coconut fibers, as well as their incorporation into cement-based matrices and textile mesh composites. The authors emphasized that coconut fibers can significantly reduce concrete density, control crack propagation, and improve fracture resistance, thereby enhancing durability and structural performance. The review also explored various treatments of fibers to improve adhesion with the cement matrix and overall composite behavior. Furthermore, the paper identified future research directions for optimizing the mechanical and durability performance of coconut fiber-reinforced cementitious materials, reinforcing the potential of agricultural by-products to contribute to environmentally friendly and high-performance construction solutions.[10]

Vignesh Kumar et al. (2023) conducted an experimental investigation on eco-friendly building blocks by utilizing coconut shells as a partial replacement for coarse aggregates. The study aimed to address the economic and environmental challenges associated with conventional construction materials, exploring sustainable alternatives through the use of agricultural waste. Concrete blocks were produced by replacing cement with 5% Alccofine and substituting coarse aggregate with coconut shells at 0%, 50%, and 100% levels. The research findings indicated that as the proportion of coconut shell replacement increased, workability, measured by slump, decreased, and the density of the concrete blocks reduced accordingly. Additionally, compressive strength was observed to decline with higher replacement levels, highlighting the trade-off between sustainability and mechanical performance. The study demonstrated that coconut shells could serve as a viable eco-friendly aggregate for lightweight construction materials, although careful optimization is required to balance strength and sustainability in practical applications.[11]

Ahmad et al. (2022) presented a comprehensive review on the mechanical and durability performance of coconut fiber-reinforced concrete (CFRC), emphasizing its potential as a sustainable alternative to synthetic fibers in construction. The study analyzed the effects of coconut fibers on both fresh and hardened concrete properties, highlighting improvements in crack prevention, flexural strength, and certain durability aspects. While the addition of coconut fibers reduced workability, the review identified 3.0% fiber content as an optimal dose for achieving high-strength performance. The authors also discussed factors influencing mechanical and durability behavior, such as fiber treatment, length, and content, providing insights into designing effective CFRC mixes. Overall, the study concluded that coconut fibers are credible, eco-friendly, and cost-effective substitutes for synthetic fibers, contributing to sustainable construction practices. [12]

Adediran et al. (2021) investigated the influence of waste glass and particulate coconut shells (PCS) on the properties of burnt clay bricks. The study incorporated PCS (−75 μm) into Orita-Obele clay at varying proportions (0–2%), while maintaining waste glass (−75 μm) at 25% by weight of clay. The effects on physical, mechanical, and thermal properties were evaluated, including porosity, water absorption, linear shrinkage, compressive strength, modulus of rupture, hardness, and thermal conductivity. Results showed that the addition of PCS and waste glass reduced porosity, water absorption, efflorescence, and wear, while improving density, strength, and thermal performance. All brick samples met the minimum strength requirements for masonry, demonstrating that combining coconut shell waste and waste glass is a viable approach for producing durable and energy-efficient fired bricks.[13]

Prakash et al. (2019) investigated the mechanical performance of eco-friendly concrete incorporating waste coconut shells as coarse aggregates and fly ash as a partial cement replacement, with additional reinforcement using steel fibers. Two concrete mixes were prepared, one entirely with coconut shell aggregates and another combining conventional aggregates with coconut shells, while 10% of cement was replaced by Class F fly ash. Steel fibers were added at 0.25%, 0.5%, 0.75%, and 1.0% by volume to enhance structural performance. The study assessed workability, density, ultrasonic pulse velocity, compressive strength, split tensile strength, flexural strength, and modulus of elasticity. Results demonstrated that steel fiber addition slightly reduced slump but increased density and significantly improved mechanical properties, with compressive strength enhanced by up to 39%, modulus of elasticity by 17%, and notable increases in split tensile and flexural strengths. Moreover, steel fibers effectively reduced brittleness in coconut shell concrete, indicating that fiber reinforcement combined with industrial and agricultural waste can yield sustainable, high-performance concrete suitable for structural applications.[14]

Giri Babu and Krishnaiah (2018) conducted a critical review on the manufacturing of eco-friendly bricks, focusing on the incorporation of various industrial and agricultural waste materials to promote sustainability in the construction sector. The study highlighted that traditional clay brick production in India consumes vast amounts of fertile soil and coal, contributing significantly to environmental degradation. To address this issue, the authors examined the use of alternative raw materials such as fly ash, marble sludge, granite sludge, stone and ceramic waste, plastic, sawdust, sugarcane bagasse ash, rice husk ash, and other agricultural residues. The review demonstrated that the inclusion of these waste materials can enhance the physical, mechanical, and thermal properties of bricks while reducing the consumption of non-renewable resources and lowering environmental impacts. The study emphasized that eco-friendly brick manufacturing not only conserves natural resources but also provides a sustainable approach to waste management and contributes to environmental protection, highlighting the potential for green building practices in developing countries.[15]

Ajay et al. (2017) investigated the development of thermally efficient, fibre-based eco-friendly bricks by incorporating coconut fibers into brick production. The study aimed to address the challenges posed by high ambient temperatures in equatorial regions by improving the thermal resistance of conventional building materials. By adding coconut fibers to the brick mix, the researchers observed improved insulation properties, which contributed to lower indoor temperatures, making the bricks suitable for hot climates. The study highlighted that integrating natural fibers such as coconut not only enhances thermal efficiency but also promotes sustainability by utilizing agricultural waste, reducing reliance on conventional materials like cement, granite, and sand. These eco-friendly bricks present a practical solution for energy-efficient construction while simultaneously contributing to waste management and environmental conservation.[16]

III. RESEARCH GAP

After reviewing the 16 previous studies, the following major research gaps have been identified:

1. Lack of Integrated Study on Fly Ash + Coconut Shell + Coconut Fiber Bricks

Most studies focus individually on fly ash bricks or coconut shell concrete or coconut fiber reinforced concrete. Very few studies have attempted to develop brick units combining all three materials simultaneously (fly ash + coconut shell + coconut fiber) and evaluate their combined performance.

2. Limited Studies on Coconut Shell as Aggregate Replacement in Brick Manufacturing

Coconut shell has been widely studied in lightweight concrete but not sufficiently explored in brick manufacturing. The effect of coconut shell particle size, percentage replacement, and pre-treatment on brick performance is still unclear.

3. Lack of Standardized Mix Design Procedure

There is no standard guideline for selecting optimal proportions of fly ash, coconut shell powder/granules, and coconut fiber content. Researchers used different proportions, making comparison difficult.

4. Limited Experimental Validation on Durability Parameters

Most studies focused on compressive strength and water absorption only. Durability parameters such as:

- sulphate resistance
- chloride penetration
- carbonation depth
- acid resistance
- freeze-thaw resistance
- long-term shrinkage and creep

have not been adequately investigated for fly ash-coconut shell-fiber bricks.

5. Lack of Microstructural Studies

Few studies used SEM, XRD, or FTIR to evaluate the microstructure and bonding behavior between coconut fiber, coconut shell particles, and fly ash cement matrix.

6. Insufficient Investigation on Fiber Treatment and Fiber Length Optimization

Coconut fiber requires treatment to improve bond strength and durability. Most studies did not focus on:

- alkali treatment effect
- fiber length variation
- fiber aspect ratio
- fiber dosage optimization
- fiber dispersion techniques

7. Absence of Field Scale Application and Masonry Prism Testing

Most studies tested individual bricks/blocks only. Masonry performance evaluation such as:

- masonry prism compressive strength
- bond strength with mortar
- wall panel behavior
- seismic performance of masonry walls

has not been investigated.

8. Limited Life Cycle Cost and Carbon Footprint Analysis

Although sustainability is claimed, only a few studies included:

- life cycle assessment (LCA)
- embodied energy analysis
- CO_2 emission reduction quantification
- cost-benefit analysis

Hence, detailed environmental impact study is still required.

CONCLUSION

This review paper critically examined 16 previous studies on fly ash-based blocks, coconut shell concrete, and coconut fiber reinforced composites. The literature confirms that fly ash is a highly effective industrial waste material for brick manufacturing due to its pozzolanic nature and strength enhancement capability. Coconut shell contributes significantly to reducing density and producing lightweight construction units, thereby improving thermal insulation and sustainability. Coconut fiber serves as an effective natural reinforcement, improving crack resistance, toughness, and ductility. However, the combined utilization of fly ash, coconut shell, and coconut fiber in brick production has not been sufficiently investigated. Existing studies lack standardized mix design procedures, long-term durability analysis, and microstructural validation. Moreover, most researchers focused on laboratory-scale testing rather than field-scale masonry applications. Therefore, significant research opportunities exist to develop optimized eco-friendly bricks incorporating fly ash, coconut shell, and coconut fiber with improved strength, reduced water absorption, and enhanced durability. The review concludes that eco-friendly bricks using these waste materials can be a sustainable and economical alternative to conventional bricks, supporting green construction and waste management practices. Further experimental research is essential to establish their long-term performance and suitability for practical construction.

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