IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.311 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 10, October 2026

DOI: 10.17148/IARJSET.2026.131047

Sustainable Brick Manufacturing Through Waste Valorisation: A Critical Review of Agricultural and Industrial By-Products as Alternatives to Conventional Cement and Natural Soil

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Abstract: The construction industry relies heavily on cement, natural soil and clay for making bricks. Making cement uses a lot of energy and releases greenhouse gases. Taking soil and clay out harms the land. Uses up resources. Researchers have looked at industrial waste as partial replacements, stabilizers or additives for sustainable bricks. This narrative review looks at 20 published studies and two additional sources. It covers sugarcane bagasse ash, sugarcane bagasse fibres, rice husk ash fly ash, waste glass, waste marble powder, paper-mill sludge and other industrial by-products used in compressed earth blocks cement-stabilized soil blocks, fired clay bricks and unfired bricks. The review compares how these materials act as cement replacement, soil replacement, stabilizer, filler or fibre reinforcement and reports on strength, water absorption, density, durability, thermal behaviour and environmental performance. Published work shows that sugarcane bagasse ash can increase the strength of some cement-stabilized soil blocks. Bagasse fibres can improve properties when used in amounts. Glass and marble wastes can change the mechanical behaviour of fired clay bricks. However performance depends strongly on composition, particle size, replacement level, soil type, compaction and curing. Differences in test procedures make direct comparison difficult. The review calls for testing, long-term durability data, life-cycle and cost assessment and large-scale validation, before widespread adoption. Waste-based bricks offer a route to conserve resources provided engineering performance and environmental safety are verified.

Keywords: bricks; cement replacement; natural soil replacement; sugarcane bagasse ash; agricultural waste; fly ash; rice husk ash; compressed earth blocks; circular economy.

1 INTRODUCTION

Bricks are one of the commonly used building materials. They are widely available, strong and work well in construction. Traditional bricks are made from clay or soil. Cement-stabilized soil blocks use cement to bind and strengthen the material. Making cement needs a lot of energy. It also releases carbon dioxide. Digging up soil and clay can damage the land. Use up natural resources [6, 7]. As the need for homes grows and people want buildings researchers have started looking for other materials. Using agricultural waste in bricks has become a major focus of study [7, 9 19].

Sugarcane bagasse is the leftover after extracting juice from sugarcane. It is often burned in sugar mills to make energy. This burning creates sugarcane bagasse ash. This ash can be rich in silica. The exact makeup of the ash depends on how it's burned and processed. When reactive silica is present with calcium hydroxide and moisture the ash can help in pozzolanic reactions [1, 6]. Early studies looked at the ash as an additive or stabilizer in stabilized and sintered earth blocks. They noted that long-term durability still needed testing [1]. Later studies looked at how the ash affects strength, water absorption and efflorescence in cement-stabilized soil blocks [2]. Others studied its impact on the bearing strength of compressed earth blocks made from loam [3]. Some research also looked at the ash combined with lime studying its effect on durability and mechanical properties in compacted soil blocks [4]. Raw bagasse fibers, which are different from the ash have also been tested as reinforcement in compressed and stabilized earth blocks. Researchers paid attention to cement content. How the blocks hold up under wet-dry cycles [5].

Beyond sugarcane bagasse other waste materials have been studied. Rice husk ash has been used in stabilized earth blocks including in life cycle assessments [10]. Fly ash and other industrial wastes have been used in clay bricks, concrete bricks. Fly ash bricks [9]. Recycled and contaminated glass has been tested in fired clay bricks [11 12 14]. Marble powder has been studied alone and with bagasse ash [15, 16 17 18]. Paper-mill sludge has also been tested [13]. There are surveys of fired and unfired bricks made from waste materials [7, 8 19 20]. A recent review, on waste-based unfired bricks highlights the need to carefully choose stabilizers check engineering performance and do sustainability assessments.

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DOI: 10.17148/IARJSET.2026.131047

Even though these studies show the potential of waste-based materials the research covers different types of bricks different wastes and different ways of replacing materials. A clear and organized comparison is needed. This would help identify what each material brings to the brick, where its limitsre what further research is needed for real-world use.

1.1 Problem statement

Traditional brick production uses a lot of resources. It often relies on energy- firing processes or cement to stabilize the bricks. At the time large amounts of agricultural and industrial waste are produced every year. These wastes are not always used properly even though they may have potential in brick making. The main issue is whether these wastes can replace cement and natural soil without hurting the strength, water resistance or long-term performance of the bricks.

1.2 Aim

This study aims to look at how agricultural and industrial waste materials can be used in brick making. The focus is especially on sugarcane bagasse ash and bagasse fibers to see how useful they can be as alternatives or additions in the brick production process.

1.3 Objectives

• To find out which agricultural and industrial wastes have been tested for use in making bricks.
• To describe how these waste materials work in bricks—as substitutes for cement, soil or clay or as stabilizers, fillers or reinforcements.
• To compare how these materials affect properties like compressive strength, water absorption, density, durability and thermal performance.
• To look at the economic advantages as well as the technical problems they bring.
• To point out missing research areas and suggest what should be studied next.

2 Review Methodology

This paper is a review of existing research on sustainable bricks, compressed earth blocks and construction materials made from waste. It is not a review.

2.1 LITERATURE SEARCH

The research used online databases: Google Scholar, ScienceDirect, SpringerLink, Wiley Online Library and MDPI. Search terms included: sugarcane bagasse ash in bricks; sugarcane bagasse fibres in compressed earth blocks; cement replacement in stabilized soil blocks; waste in brick manufacturing; fly ash and rice husk ash in bricks; waste-based unfired bricks and alternative stabilizers; and compressive strength, water absorption and durability of earth blocks. The search was carried out in October 2026. Only studies published between 2009 and 2024 were considered, with a focus on sugarcane bagasse ash, agricultural waste, industrial waste and sustainable brick production.

2.2 Selection criteria

The review prioritized peer-reviewed studies on brick making, soil stabilization or waste-based binders. Experimental studies were used for data on performance while review papers helped identify trends, limitations and gaps. Studies on concrete or mortar were included only to explain chemical or binder concepts—these results were not used as brick data. A total of 30 papers were found initially. After checking titles, abstracts and how relevant they were, to the topic 20 papers were chosen for the review.

2.3 Comparative analysis

The literature we looked at was sorted by type of waste material of brick how the waste was used how much was added, curing conditions and what performance tests were done. In each case we noted whether the waste replaced cement, natural soil, clay, sand or some other part of the brick mix. Since the studies used materials and testing methods we didn't combine their numbers into one big comparison.

3. OVERVIEW OF THE REVIEWED LITERATURE

The 20 main sources fall into five groups (Table 1). Sources [1 2, 3 4 5] and [15] focus on sugarcane by-products. Sources [6, 7 8 9 19 20] are reviews or broad surveys. Source [10] talks about rice husk ash. Sources [11 12 13 14] look at waste glass and paper-mill sludge. Sources [15, 16 17 18] cover marble waste.

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Table 1: Distribution of the reviewed sources

Group	Source	Brick system	Main focus
Sugarcane bagasse ash	[1, 2, 3, 4, 15]	Stabilized or compressed earth blocks; fired clay bricks (with marble)	Strength, absorption, efflorescence, bearing strength, durability
Sugarcane bagasse fiber	[5]	Compressed stabilized earth blocks	Strength and wet–dry durability at varying cement content
Rice husk ash	[10]	Compressed stabilized earth blocks	Strength, durability, life cycle assessment
Waste glass, paper mill sludge	[11, 12, 13, 14]	Fired clay bricks	Physical and mechanical properties, firing demand
Waste marble	[15, 16, 17, 18]	Fired clay bricks	Physical and mechanical properties, lightweight and energy-efficient bricks
General and review papers	[6, 7, 8, 9, 19, 20]	Fired, unfired, fly ash, clay and concrete bricks	Production methods, binders, compaction, circular economy, scale-up

4. REPLACEMENT MECHANISMS IN SUSTAINABLE BRICK MANUFACTURING

How well a waste material works in bricks depends on its physical and chemical traits and what role it plays in the mix. Waste materials aren't interchangeable just because they're both "waste." You have to think about what they're replacing and what kind of brick you're making**.**

4.1 Partial replacement of cement

Cement is what holds stabilized soil blocks together. Processed bagasse ash and fly ash can take the place of some cement long as their properties and the mix design allow it [2, 6 9 10]. The silica and alumina in these ashes can react under the conditions to form binding compounds. These help hold the particles and reduce the number of pores which makes the brick stronger.. Not all ashes react well. Processed ash, too much replacement or not enough curing can actually weaken the brick. So the right amount to use must be tested for each material and soil type.

4.2 Replacement or modification of soil and clay

Soil is the main part of compressed earth blocks. It's not always. Possible to replace it. Sometimes waste materials are used to replace part of the soil or clay or to change how the particles are sized. Examples from the reviewed papers include marble powder and glass in fired clay bricks [11, 12 14 16 17 18] and residues in clay brick production [13, 20]. How well this works depends on particle size, soil plasticity, chemical makeup how well it compacts and whether there's a binder. The word "soil" should be clearly defined in each study. For example red soil is natural. Red mud is waste from the aluminum industry. Confusing the two can lead to conclusions.

4.3 Fibre reinforcement using bagasse

Raw bagasse fibres are not the same as bagasse ash. Fibres can help stop cracks from spreading spread out stress and hold things together. Their effect depends on how long they're how fine they are how much is added how evenly they're spread and how well they stick to the soil. Much fibre can make the mixture more porous absorb more water and be harder to mix. So raw bagasse fibres should be seen as reinforcement not as a substitute for cement.

4.4 Fluxing, filler and firing effects in fired bricks

In fired clay bricks, waste materials like glass can act as fluxes or fillers. Studies on glass looked at how it affects the physical and mechanical properties of fired bricks [11, 14]. Other work on glass dust from waste showed it might improve performance and lower firing temperature [12]. Marble waste has been studied as a replacement for regular raw materials [16, 17] and as a way to make lighter possibly more energy-efficient bricks [18].

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4.5 Alternative binder systems

Geopolymer and other activated bricks use reactive materials like certain fly ashes or slags, with alkaline activators to form a binding gel . These can cut down on cement use.. Their environmental benefit depends on how the raw materials are made how the activators are produced and how far the materials are transported. Just using an industrial by-product doesn't automatically make a brick more sustainable.

5. PROPERTIES AND PERFORMANCE OF WASTE MATERIALS IN BRICKS

5.1 Sugarcane bagasse ash

Bagasse ash is made when bagasse is burned to produce energy. Its makeup and how it reacts depend on the heat level how long it burns, any impurities and what happens after it is burned.

Reported benefits. If the silica in the ash is active enough it can aid reactions. Tiny ash particles can pack better which may let us reach the desired strength using cement and it also keeps waste out of landfills.

A review of using it in stabilized and sintered earth blocks and tiles found it to be rich in silica [1]. Another review connected it to low-carbon construction [6].

Experimental evidence. James and colleagues [2] examined mixes with 4% and 10% cement. Added 4%, 6% and 8% ash by weight of dry soil. For the mix with 4% cement and 8% ash the block reached 2.95 MPa, than 2.59 MPa for the block without ash. In the 10% cement mix strength increased from 5.42 MPa to 5.85 MPa when 8% ash was added. These results show that ash can help in these mixes but they do not prove that any particular percentage is always best or that cement can always be fully replaced. The same research also looked at water absorption and efflorescence proving that strength alone is not enough [2]. Salim and colleagues [3] studied bagasse ash to boost the bearing strength of compressed earth blocks made from loam soil while another study looked at combining it with lime to improve durability and mechanical properties of compacted blocks [4]. Salim and colleagues [3] examined the addition of 3

Limitations. The ash can vary a lot. If it is not processed well its reactivity drops. It can absorb water and it takes enough curing time to build strength. Before using it we need chemical tests and tests that match the mix [1, 2].

5.2 Sugarcane bagasse fibres

Bagasse has cellulose, hemicellulose and lignin. Its fibrous structure makes it good for reinforcement.

Kumar and Barbato [5] tried 0%, 0.5% and 1.0% fibre in mixes with cement levels. They found that adding 0.5–1.0% fibre to blocks that had 12% cement raised strength while keeping durability intact in the conditions they tested. Fibres can still soak up water come in sizes and qualities and break down in some situations so we must look at how they spread and how they behave over time.

5.3 Rice husk ash

Rice husk ash may contain a lot of silica if it is burned correctly. It can be used in soil blocks and geopolymer systems. Researchers have looked at using it in stabilized earth blocks with cement, checking strength, durability and life-cycle impact [10]. If the burning is not done properly the ash may have non-reactive silica or leftover carbon so we need to confirm how it affects water absorption, strength and durability.

5.4 Fly ash and other industrial by-products

Fly ash is a residue from burning coal. It can act as a cementitious material, part of a lime binder or a geopolymer precursor depending on its mix, fineness and reactivity. Researchers have reviewed its reuse in clay, concrete and fly ash bricks from a circular-economy perspective [9]. Another review looked at using by-products in fired and unfired bricks noting environmental and practical benefits [7]. Fly ash differs from source to source; some types need activation. We must test for harmful elements. Other industrial by-products are discussed in studies on low-cost bricks [19] and clay brick production [20]. Red mud, mentioned in the supporting literature is very alkaline. May leach, so it needs environmental testing and should not be called a replacement for natural red soil without a defined mix and test evidence.

5.5 Waste glass and paper-mill sludge

Researchers have looked at replacing part of the material with recycled glass to see how it changes the physical and mechanical properties of fired clay bricks [11, 14]. They also studied waste-contaminated glass dust to see how it affects performance and firing needs [12]. Paper-mill sludge has been tested as another material and its influence on brick properties has been evaluated [13]. The data show that the best amount of waste depends on the material mix and the firing conditions.

Loryuenyong and colleagues [11] reported that bricks containing 15–30 wt.

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5.6 Waste marble powder

Marble powder has been studied as a replacement for conventional raw materials, in brick.
manufacture [16] has been studied for its effect on the mechanical properties of fired clay bricks [17] and for its role in producing lightweight energy-efficient clay bricks [18]. A hybrid mix of marble powder and bagasse ash has also been examined in clay bricks as a way to reuse two wastes simultaneously [15].

5.7 Comparative summary

These materials perform functions. They should not be treated as equivalent without identifying what is replaced and what the final brick system will be.

6. ENGINEERING PROPERTIES OF SUSTAINABLE BRICKS

6.1 strength

Compressive strength depends on binder content, soil characteristics, moisture, compaction pressure, curing and pore structure. Evidence from [2] shows that bagasse ash can raise strength in some cement-stabilized mixes while [5] concerns fibres, than bagasse ash so bagasse ash results are relevant.

Table 2: Comparison of waste materials

Material	Main role	Potential benefit	Main concern
Bagasse ash	Supplementary binder or filler	May reduce cement demand and aid strength	Variable reactivity; water uptake
Bagasse fibre	Reinforcement	Crack control; some strength gain	Water absorption; durability of fibres
Rice husk ash	Silica-rich pozzolan	Possible strength contribution	Quality depends on burning
Fly ash	Binder component or geopolymer precursor	Cement reduction; waste reuse	Variability; curing and activation needs
Waste glass	Fluxing filler in fired bricks	Possible property improvement and lower firing demand	Composition and contamination
Marble powder	Partial clay replacement or filler	Lighter, possibly more energy-efficient bricks	Mix compatibility; particle size
Paper-mill sludge	Alternative raw material	Waste diversion	Effect on brick properties must must be verified

6.2 Water absorption

Water absorption shows the structure of the brick and affects strength and durability. Bagasse ash may improve particle packing. Its effect on absorption depends on the mix [2]. Fibres can change the structure and absorption [5]. Absorption must be checked along with strength and durability not alone.

6.3 Density and porosity

Dry density affects the weight, handling, strength and thermal behavior of bricks. Fine replacements can increase packing density.. Poorly dispersed fibres can create voids. Lower density is useful when reduced self-weight is needed, as in marble-waste bricks [18].. Too much porosity can weaken the brick and allow more water to enter.

6.4 Durability

Durability includes resistance to dry cycles, abrasion, cracking and long-term wetting. Barbato [5] tested wet–dry durability using mass loss, dry density, absorption and wet strength. These tests are important because a brick that looks good in the lab might not last in use. The long-term durability of ash blocks still needs more research [1].

6.5 Thermal performance

Thermal behavior depends on porosity, density, moisture content and composition. Lower density does not always mean thermal performance. So direct thermal testing or reliable measurements are needed. Some studies suggest energy efficiency for marble-waste bricks [18] but thermal data must be collected and reported where possible.

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7. ENVIRONMENTAL AND ECONOMIC CONSIDERATIONS

Environmental benefits include less use of virgin materials better use of waste and lower cement or kiln energy in suitable brick systems. Reviews link waste-based construction materials to lower-carbon building [6]. A life cycle assessment for rice husk ash earth blocks has been done [10]. Economic benefits come when waste is available and cheaper than materials.. Costs include drying, grinding, sieving, transport, chemical treatment, quality control and curing. A full assessment should compare cost and environmental impact per unit of performance against a conventional brick. Environmental safety like leaching from waste must also be checked.

8. EVALUATION FRAMEWORK

The following step-by-step method is proposed for evaluating materials in brick making.
1. Define the brick system. Say whether the product is a fired clay brick, cement-stabilized block compressed earth block or geopolymer brick. Also state the role of the material being replaced.
2. Characterize the materials. Record particle size, chemical composition, moisture and physical features. For soil include grading and plasticity. For ash note composition and processing. For fibres give length, dosage and shape.
3. Define dosage. Separate additives from replacements. State the percentage of cement, soil or total dry mix replaced.
4. Test performance. Compare strength, water absorption, density, shrinkage, durability and thermal behavior where data exist.
5. Assess practicality. Look at availability, quality consistency, transport distance, processing energy, cost, emissions and safety.
6. Identify the mix. The best mix is not always the strongest. It should meet the application needs while balancing durability, cost, resource use and environmental benefit.
Proposed workflow: waste selection → material characterization → mix design → brick production and curing → performance testing → economic assessment → suitability for application.

9. RESEARCH GAPS

9.1 Non-comparable studies
Studies vary in soil type, stabilizer amount, compaction method, curing process and test procedures. This makes direct comparison hard [8]. Future work should use mix reporting, standard tests and common performance indicators.

9.2 Limited long-term evidence
Most studies focus on age strength and water absorption.. Long-term performance under repeated wetting and drying or real-world conditions is less studied [1]. More durability and in-service testing is needed.

9.3 Variability of waste quality
The quality of bagasse ash fly ash and rice husk ash can vary based on source and how they were processed. This leads to brick quality. Standard procedures for characterizing and controlling waste quality are needed.

9.4 Uncertain optimum dosage
A dosage that works well in one soil or binder system may not work in another. Dosage studies should consider soil type, compaction, curing and final performance.

9.5 Incomplete environmental and economic assessment
Using waste is not automatically better or cheaper. Processing, transport and chemicals can change the impact. Life-cycle and cost assessments with functional units and system boundaries are needed [6 9, 10].

9.6 Limited large-scale validation
Lab results do not prove that a material is suitable for projects. Industrial production, quality control, construction practices, standards and market acceptance matter [8]. Guidelines, for production, quality verification and safe use are necessary.

9.7 Distinguishing cement replacement from soil replacement
Some studies add waste to cement-stabilized soil others replace part of the soil and others use waste as a binder. Each choice changes strength, cost and sustainability. Studies should be sorted by what's replaced how much is replaced and how the bricks are made.

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10. CONCLUSION

Agricultural and industrial wastes give a chance to make brick manufacturing more efficient. Sugarcane bagasse ash works as a stabilizer in cement-stabilized soil blocks. Raw bagasse fibres can improve some properties when used in the amounts. Rice husk ash, fly ash, glass, marble and other by-products offer ways to cut down on cement, clay and natural soil in both unfired and fired bricks.

Results vary with each material and mix. Performance depends on composition, replacement level, soil type, compaction, curing and service conditions. A higher compressive strength does not always mean water absorption, better thermal behaviour or longer service life.

Future work should focus on testing, long-term durability, quality control, life-cycle assessment and economic feasibility. Future work must also clearly separate cement replacement, soil replacement, supplementary addition and fibre reinforcement. Waste-based bricks can support construction where waste-based bricks meet the environmental needs of each application. Wider use will depend on performance, safe use, cost-effectiveness and reliable high-quality production.

Credit authorship contribution statement

Harshwardhan Desai: Investigation, Data curation, Visualization, Writing – draft.

Funding

This research did not receive any grant from funding agencies in the public, commercial or not-for-profit sectors.

Data availability

No new data were generated in this review. All information discussed is available in the cited literature.

Declaration of AI use

During the preparation of this review paper the authors used ChatGPT (OpenAI) to help with language editing, drafting organising the literature review and improving the clarity and structure of the manuscript. The authors. Revised the AI-assisted content verified the cited sources and reported findings against the original publications and take full responsibility, for the accuracy, integrity and final content of this work.

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