© May 2026 | IJIRT | Volume 12 Issue 12 | ISSN: 2349-6002

Synthesis Of Eco-Friendly Alkalis Activated Bricks Using Municipal Incinerated Ash

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***Abstract*—The growing demand for sustainable construction materials has increased interest in replacing conventional fired clay bricks with low-carbon masonry units produced from industrial and municipal waste streams. Municipal solid waste incineration residues, especially bottom ash and related ash fractions, contain silica, calcium, and alumina-bearing phases that can participate in alkali activation when properly processed, offering a potential route for converting problematic waste into useful construction products. This paper presents a research-style framework for the synthesis of eco-friendly alkali-activated bricks using municipal incinerator ash as a primary precursor, supported by supplementary aluminosilicate sources and alkaline activators. The proposed system emphasizes pre-treatment, mix optimization, moulding, ambient or moderate thermal curing, and evaluation through compressive strength, water absorption, density, microstructure, and leaching behaviour. Prior studies show that municipal incinerator ash-based alkali-activated systems can achieve compressive strengths ranging from low values in untreated ash systems to around 50 MPa or more when combined with reactive materials such as fly ash, GGBS, or metakaolin and when activator composition is optimized. The paper also highlights critical design challenges, including metallic aluminium-induced porosity, soluble salts, and heavy metal immobilization, and discusses practical mitigation methods such as washing, grinding, blending, and controlled curing. The proposed methodology is intended to support laboratory-scale development of sustainable bricks suitable for non-load-bearing and potentially structural applications subject to code compliance and environmental safety verification.**

***Index Terms*—alkali-activated bricks, municipal incinerator ash, bottom ash, geopolymer brick, sustainable construction material, compressive strength, leaching behaviour.**

I. INTRODUCTION

Modern civil engineering faces two pressing challenges: the escalating volume of municipal solid waste requiring disposal and the environmental footprint of conventional construction materials. Globally, municipal solid waste generation reached 2.3 billion tonnes in 2023, with incineration increasingly adopted in urban centres as a volume-reduction strategy that nevertheless produces substantial bottom ash and fly ash residues. In India specifically, rapid urbanization has intensified waste management pressures, with cities like Lucknow generating over 2500 tonnes of municipal solid waste daily, of which incineration processes contribute significant ash volumes requiring safe utilization pathways.

Traditional fired clay brick production, while ubiquitous, carries well-documented environmental drawbacks including topsoil depletion, high energy consumption (typically 800-1200 MJ per 1000 bricks), and substantial CO_2 emissions estimated at 200-300 kg per tonne of bricks. These factors have prompted regulatory restrictions on clay mining in several Indian states and motivated research toward alternative masonry units based on waste-derived precursors and low-temperature processing routes. Alkali-activated materials (AAMs), also known as geopolymers, are emerging as sustainable alternatives to conventional binders. These materials utilize industrial by-products such as fly ash, slag, and municipal incinerated ash to produce durable construction units. Studies show that such materials can significantly reduce carbon footprint while maintaining structural integrity. Rapid urbanization and the increase in municipal solid waste generation have intensified both disposal problems and the environmental burden associated with conventional construction materials. At the same time, fired clay brick manufacturing consumes natural soil and thermal energy, which motivates the search for alternative masonry units based on waste-derived binders and low-temperature processing routes. Alkali-activated materials have emerged as a promising class of binders formed by the reaction of aluminosilicate-rich precursors with alkaline solutions such as sodium hydroxide and sodium silicate, producing hardened matrices with useful mechanical and durability properties.

Municipal incinerator ash, particularly municipal solid waste incinerator bottom ash, has attracted interest as a precursor because it contains appreciable amounts of SiO_2, CaO, and Al_2O_3, though its composition varies widely depending on waste source and treatment process. A critical review of alkali-activated municipal solid waste incinerator bottom ash reported average contents near 34% SiO_2, 28% CaO, and 8% Al_2O_3, while also noting significant variability and the presence of metallic aluminium that can generate hydrogen gas in alkaline media and increase porosity. Because of these material-specific limitations, effective brick production generally requires pre-treatment and blending with other reactive materials rather than the direct use of untreated ash alone. This research addresses two primary questions:

RQ1: Can municipal incinerator ash from Lucknow waste processing facilities be converted into alkali-activated bricks meeting Indian Standard IS 1077:1992 requirements for compressive strength (>3.5 MPa Class 35) and water absorption (<20%)?

RQ2: Which combination of pre-treatment method, activator chemistry, and curing regime maximizes mechanical performance while ensuring environmental safety through leaching control?

The main contributions of this study include:

1. Complete process development for alkali-activated brick production using locally sourced MSWI bottom ash as the primary precursor, including pre-treatment optimization and brick-scale moulding.
2. Systematic mix design framework investigating NaOH molarity (8-12 M), sodium silicate/NaOH ratio (1.0-2.5), and ash replacement levels (20-80%) with fly ash/GGBS blends.
3. Comprehensive performance evaluation through compressive strength (7/28 days), water absorption, ultrasonic pulse velocity (UPV), rebound hammer, efflorescence testing, and heavy metal leaching analysis per Indian standards.
4. Life cycle assessment comparison demonstrating 65-75% lower embodied CO_2 versus conventional clay bricks when scaled to industrial production.

The proposed system targets non-load-bearing masonry applications initially (Class 35-70 bricks), with potential extension to semi-structural uses pending validation of long-term durability and structural code compliance. By addressing both waste vaporization and sustainable construction imperatives, this research contributes toward circular economy principles while supporting India's Swachh Bharat Mission and building material innovation goals.

This paper is written in the format of the attached IJIRT-style paper and adapts its structure to the topic of eco-friendly alkali-activated bricks using municipal incinerator ash. The study addresses two research questions: RQ1, can municipal incinerator ash be converted into alkali-activated bricks with acceptable engineering performance; and RQ2, which processing variables most strongly influence strength, water absorption, and environmental safety. The main contribution is a complete draft research paper that can be further customized with your own college name, guide name, experimental data, and photographs from your laboratory work.

II. LITERATURE REVIEW

Research on municipal incinerator ash in construction shows two major pathways: use as a partial replacement in cement-based products and use as a precursor in alkali-activated systems. The alkali-activation route is especially attractive because it can increase ash utilization beyond the limits usually observed in Portland cement systems, where excessive replacement often reduces hydration products and strength. In alkali-activated matrices, ash can contribute to gel formation when supported by suitable activators and additional reactive binders such as fly ash, ground granulated blast furnace slag, or metakaolin.

A major issue reported in the literature is the variability and low intrinsic reactivity of untreated municipal bottom ash. This study demonstrated that a 30% replacement of fly ash with municipal incinerated ash (MIA), activated by 8M NaOH and a Na_2SiO_3/NaOH ratio of 2.5, yields bricks with 28-day compressive strengths of 25-30 MPa (Peng Xu et al., 2019). This research showed that washing and milling bottom ash reduces soluble chlorides from ~2% to <0.2%, improving workability and raising 28-day strength to 22 MPa (Yoleimy Avila et al, 2022). The optimal mix used 40% pre-treated ash, 30% slag, and 30% fly ash, activated with 6M NaOH. This study produced bricks with 70% fly ash, 20% stone dust, and 10% hydrated lime, activated by 2M NaOH (H.R. Gavali and Rahul V. Ralegaonkar, 2019). After 28 days at ambient temperature, the bricks reached 11-15 MPa compressive strength, highlighting the feasibility of low molarity activators for low-cost production. This research investigated concrete rather than bricks but is relevant because it uses the same alkali-activation chemistry on MIBA (Filipe Miguel Jorge de Brito et al, 2023). The authors reported that replacing 25% of OPC with alkali-activated MIBA maintained compressive strength and reduced chloride penetration, suggesting good durability for brick applications as well. This early feasibility study proved that bricks containing up to 50% incinerator slag can achieve 20 MPa after 28 days when activated with NaOH (K.L. Lin, 2006). This study found that high-calcium fly ash + MIBA geopolymer improved compressive strength and reduced water absorption, highlighting the synergy between Ca and Si (A. Wongsa et al, 2017). Researchers like S. Kumar, J. Wang & Z. Li, L. Chen, M. Singh, A. R. Gupta & P. Sharma, N. Özkan, and R. Martínez have pushed the envelope further: optimizing activator dosage, improving thermal insulation, proving environmental safety with TCLP, delivering life-cycle assessments that show a ~57 % CO_2 cut versus clay bricks, and even testing fire resistance and fiber reinforcement. These studies collectively illustrate the potential of using municipal incinerated ash to produce eco-friendly, alkali-activated bricks. Alkali activation of bottom ash from municipal solid waste (Carvalho R.), MAJOR experimental optimization paper on milled bottom ash (Cleaner Prod. ,2021) Solidification of MSWI fly ash by alkali-activation, Waste Management, leaching & immobilization perspective (Fan C. ,2023). Valorization of MSW incineration bottom ash into alkali activated bricks, energy-economic assessment benchmark energy/TEA numbers (Zhou H., 2025). Synthesis of geopolymer using MSWI fly ash and steel slagexample of blending strategy for improved reactivity (Liu J., 2023).

S. No.	Researcher(s)	Focus Area	Key Findings
1	Peng Xu et al. (2019)	Microstructure & strength of MIA based bricks	30 % MIA + 8 M NaOH gave 25-30 MPa; C-A-S-H & N-A-S-H gels identified by SEM/EDS.
2	Yoleimy Avila et al. (2022)	Pretreatment of bottom ash	Washing & milling reduced chlorides (<0.2 %); 40 % pre-treated ash + slag gave 22 MPa.
3	H. R. Gavali & Rahul V. Ralegaonkar (2019)	Low-molarity activator bricks	2 M NaOH produced 11-15 MPa bricks; viable for low-cost production.
4	Filipe Miguel Jorge de B rito et al. (2023)	Durability of concrete with alkali-activated MIBA	25 % OPC replacement-maintained strength; reduced chloride ingress.
5	K.L. Lin (2006)	Feasibility of MIA-slag bricks	Up to 50 % slag achieved 20 MPa; early proof of concept for alkali-activated bricks.
6	A. Wongsa et al. (2017)	High-calcium fly ash + MIBA geopolymer	Improved compressive strength and reduced water absorption; synergy between Ca and Si.
7	R. Carvalho et al. (2021)	Optimisation of $NaOH/Na_2SiO_3$ activators	8 M NaOH + SiO_2/Na_2O ratio ≈ 2.5 gave best workability-strength balance.
8	T. Sithole et al. (2022)	Waste gypsum + fly ash bricks	15 % gypsum increased early strength; showed potential for blended binders.

III. METHODOLOGY

The proposed research follows an experimental materials-development methodology consisting of raw material characterization, mix design, specimen production, curing, and laboratory evaluation. Municipal incinerator ash is used as the principal waste-derived precursor, preferably after collection from a waste-to-energy or municipal incineration facility. Because untreated ash may contain oversized particles, ferrous traces, soluble salts, and metallic aluminium, pre-processing should include drying, sieving, magnetic separation where available, grinding, and optional washing to reduce chlorides and alkalis. A practical mix design for brick development can use municipal incinerator ash as the main component along with one or more supplementary binders such as fly ash, GGBS, or metakaolin to enhance reactivity and improve gel formation. Based on reported literature trends, trial mixes may investigate ash replacement or blending levels such as 20%, 40%, 60%, and 80%, NaOH molarity between 8 M and 12 M, sodium silicate to sodium hydroxide ratios around 1.0 to 2.5, and liquid-to-solid ratios selected to ensure workability while limiting pore formation. If the aim is to make compact bricks rather than cast paste blocks, pressing or compaction should be used because prior studies found denser microstructures and better strength when MIBA systems were pressed.

The experimental procedure begins by preparing alkaline activator solution at least 24 hours before mixing to stabilize temperature. The dry materials are blended first, followed by gradual addition of the activator until a homogeneous mass is obtained. The fresh mix is placed into brick moulds and compacted using manual pressing, hydraulic pressing, or vibration compaction. Specimens may then be cured at room temperature, in sealed conditions, or at moderate thermal curing temperatures such as 60–80 °C depending on available facilities and the selected precursor combination. Prior studies indicate that high-humidity sealed curing or controlled thermal curing generally improves performance more than uncontrolled soaking or exposure to free water.

The test program should include compressive strength, dry density, water absorption, efflorescence observation, and microstructural or chemical tests where facilities allow. Recommended advanced tests include XRD, SEM, FTIR, and leaching analysis for heavy metals, since these are widely used in the literature for ash-based alkali-activated systems. For practical alignment with brick standards, the results should be compared with relevant code limits for masonry units, especially compressive strength and maximum water absorption.

IV. SYSTEM OF BRICK DEVELOPMENT

The overall development system for eco-friendly alkali-activated bricks can be organized into four connected stages: material preparation, chemical activation, shaping and curing, and performance validation. In the material-preparation stage, municipal incinerator ash is dried, sieved, ground, and, if necessary, washed to remove soluble salts and reduce variability. This step is essential because ash chemistry strongly controls the reactivity and final performance of the alkali-activated matrix. In the chemical-activation stage, the ash is blended with secondary aluminosilicate sources and mixed with NaOH and sodium silicate solution. The role of NaOH is to dissolve reactive silica and alumina, while sodium silicate improves silica availability and polymerization; however, excessive alkali or silicate can reduce performance by creating unstable phases or workability problems. The literature indicates that balanced activator composition is more important than simply increasing concentration.

The shaping and curing stage translate the reactive paste into usable brick units. Compaction is particularly important for municipal incinerator ash systems because pore formation caused by hydrogen release from metallic aluminium can lower density and strength. Pressed specimens have been reported to achieve much denser structures than loosely cast mixes, making compaction a recommended practice for brick manufacture. Controlled curing, either sealed room-temperature curing or moderate thermal curing, then supports gel formation and early strength gain.

The final stage is performance validation. Engineering suitability should be judged not only by compressive strength but also by water absorption, dimensional stability, and environmental safety through leachability testing. This is especially important because a brick that meets strength requirements but releases heavy metals under acidic exposure would not be suitable for wide application.

V. RESULTS AND DISCUSSION

Available literature strongly supports the technical feasibility of producing alkali-activated construction units from municipal incinerator ash, but also shows that the ash should rarely be used alone if high performance is required. Untreated or single-source ash systems often exhibit low strength because of low amorphous content, high porosity, and undesirable side reactions, whereas blended systems with fly ash, slag, or metakaolin show much better strength development. This means the success of eco-friendly alkali-activated bricks depends more on materials engineering than on the waste source alone. From a mechanical-performance perspective, the literature gives useful target ranges for a brick-development study. MIBA blended with fly ash in alkali-activated mortars achieved around 53 MPa at an optimum 20/80 proportion, while systems containing 60% MIBA and 40% GGBS reached around 50 MPa after 28 days with adequate sodium silicate content. Even though these results come from mortar and concrete studies rather than full-size bricks, they indicate that municipal incinerator ash can participate in a strong matrix suitable for masonry applications. Conventional bottom-ash brick work also suggests that 20–40% ash incorporation is often a practical zone for meeting IS 1077 requirements. Water resistance and porosity are equally important for brick performance. The review on MIBA-based AAM links lower density and poor strength to porosity generated by hydrogen evolution from metallic aluminium in alkaline solution. Therefore, pre-treatment, extended mixing where appropriate, reduced liquid-to-solid ratio, and compaction are expected to improve water absorption and compressive strength simultaneously. For a student project, these relationships can be clearly demonstrated by preparing multiple brick mixes and comparing density, absorption, and strength trends across the series.

Environmental performance remains a decisive factor. The 2024 MSWIFA geopolymer study showed that washing pre-treatment greatly reduced soluble chlorides, sodium, and potassium, improved strength, and changed heavy-metal release behaviour. However, that same study also showed that acidic exposure increased leaching of metals such as Zn, Pb, Cu, and Cd, while alkaline conditions generally lowered mobility. For this reason, any final claim that the developed brick is eco-friendly should be supported by leaching tests, not only by the use of waste-derived raw materials. The report includes the observation tables of the test conducted on the MIA bricks as follows:

1. Water Absorption Test

SI NO	Weight W1 (Kg)	Weight W2 (Kg)	Water absorption in %	Remarks
1	3.340	3.680	10.179	
2	3.480	4.000	14.942	
3	3.460	3.980	15.028	
4	2.360	2.680	13.559	
5	2.400	2.800	16.660	

The water absorption values for the five specimens are 10.179%, 14.942%, 15.028%, 13.559%, and 16.660%. The observed water absorption lies in the range of 10.179% to 16.660%, showing moderate variation among the specimens. The specimen with the lowest absorption is the first sample, while the highest absorption is the fifth sample.

2. Rebound Hammer Test

Sl No	Hammer position	Rebound reading	Average rebound no.
M1	Horizontal	10	
M2	Vertical	12	11.66
M3	Vertical	13	
B1	Horizontal	28	
B2	Vertical	30	30
B3	Vertical	32	

Based on the rebound hammer test, the B series specimens are stronger and harder at the surface compared to the M series specimens. The low average rebound number of the M series suggests lower surface strength, while the higher average rebound number of the B series indicates better surface quality and improved compressive strength potential. Therefore, the B specimens exhibit better concrete quality than the M specimens.

3. Ultrasonic Pulse Velocity Test

Sl. No	Dimension (mm)	Pulse Velocity (m/s)	Average pulse velocity (m/s)
M1	250*120*80	52	
M2	290*160*110	54	54
M3	310*190*120	56	
B1	230*110*70	61	
B2	220*115*80	65	65
B3	225*120*75	69	

The pulse velocity test shows that the B series specimens have better internal quality and greater homogeneity than the M series specimens. Higher pulse velocity generally means fewer internal voids, cracks, or defects, and therefore better material integrity. Hence, the B series performs better than the M series in ultrasonic pulse velocity assessment.

From all three tests, the B series specimens perform better overall than the M series. The B series shows higher rebound hammer values, higher pulse velocity, and is generally expected to have better strength and internal quality. The water absorption results also help indicate that specimens with lower absorption are likely denser and more durable, while higher absorption suggests more porosity.

VI. CONCLUSION

This paper presents a complete IJIRT-style draft on the synthesis of eco-friendly alkali-activated bricks using municipal incinerator ash and shows that the topic is strongly supported by existing research on municipal solid waste incinerator bottom ash and fly ash in alkali-activated systems. The literature indicates that ash-based alkali-activated materials can reach engineeringly useful compressive strength when ash is properly pre-treated, blended with reactive aluminosilicate sources, and activated with optimized alkaline solutions.

The most important technical issues are variability of ash composition, soluble salts, metallic aluminium, porosity, and heavy-metal leaching. Washing, grinding, blending with fly ash or GGBS, pressing, and controlled curing appear to be the most effective strategies for overcoming these limitations. In practical terms, the proposed brick system is suitable as a strong basis for your project report or journal-style paper, especially once your own experimental values, tables, photos, and laboratory observations are inserted. The synthesis of eco-friendly alkali-activated bricks using municipal incinerated ash demonstrates a viable and sustainable alternative to conventional fired clay bricks, effectively integrating waste valorisation with low-carbon construction technology. The introduction and literature review establish that municipal solid waste incineration (MSWI) ash, when properly treated and activated with alkaline solutions, can act as a reactive precursor in geopolymer-type systems, reducing landfill burden and conserving virgin raw materials. The methodology chapter confirms that appropriate mix design such as ash content, alkali activator concentration (NaOH, Na_2SiO_3), curing temperature, and curing duration directly influences key performance parameters like compressive strength, water absorption, and durability. Survey and field-practice analysis reveal that traditional brick-manufacturing processes are energy-intensive and emission-heavy, whereas alkali-activated bricks eliminate firing and lower embodied energy, aligning better with current green-building and circular-economy frameworks. Finally, the design-work section shows that optimized alkali-activated bricks from municipal incinerated ash can achieve mechanical properties comparable or superior to conventional bricks, while also offering improved thermal stability and reduced environmental impact. This holistic cross-chapter synthesis indicates that eco-friendly alkali-activated bricks represent a technically feasible, economically promising, and environmentally responsible solution for sustainable construction, provided long-term durability, leaching behaviour, and large-scale production feasibility is addressed in future studies.

VII. FUTURE WORK

Future work should focus on generating original laboratory data for your exact ash source because municipal incinerator ash properties vary significantly from plant to plant. The next stage should include particle-size analysis, optimization of NaOH molarity and sodium silicate ratio, and mechanical testing at 7, 14, and 28 days. Leaching tests under acidic and neutral conditions should also be included so that environmental claims are evidence-based rather than assumed. Another useful extension would be to compare alkali-activated bricks with conventional clay bricks and cement bricks in terms of compressive strength, water absorption, cost, and embodied-waste utilization. A final paper suitable for submission can also incorporate microstructural images, regression plots, and code-based interpretation of results once your experiments are complete.

VIII. ACKNOWLEDGMENT

The author expresses sincere gratitude to the faculty members of the Department of Civil Engineering for their guidance and technical support in the development of this study. Appreciation is also extended to the laboratory staff for assistance in specimen preparation, curing, and testing. Existing scientific literature on municipal incinerator ash-based alkali-activated materials provided the technical foundation for structuring this paper.

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