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Investigation of Mechanical Properties of Hollow Bricks Incorporating Aerated Aggregates: A Polymer-Cement Composite Approach

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Abstract

The rapid advancement of construction technologies has necessitated the development of lightweight, thermally efficient, and sustainable building materials. Hollow bricks, due to their inherent voids, offer substantial reductions in dead load and enhanced insulation properties. However, their mechanical performance often falls short when compared to conventional solid bricks. To address this limitation, this study explores the synergistic integration of aerated aggregates and polymer-cement composites (PCCs) in hollow brick production. Aerated aggregates such as foamed glass and expanded clay provide the benefits of low density and thermal insulation but typically compromise compressive strength. Meanwhile, polymer additives like Styrene-Butadiene Rubber (SBR), Acrylic Emulsions, and Epoxy Resins significantly improve the bond strength, flexibility, water resistance, and crack-bridging ability of cementitious composites. This research combines these materials to produce innovative hollow bricks with improved structural and durability characteristics. Five distinct mix designs incorporating varying proportions of polymers and aerated aggregates were tested. Comprehensive laboratory evaluations included compressive strength, flexural strength, water absorption, impact resistance, thermal conductivity, and microstructural analysis using SEM and DSC/TGA techniques. The findings revealed that the optimal combination (Mix M3: 90% cement, 10% epoxy, and 20% aerated aggregates) exhibited a 26% increase in compressive strength and nearly 40% reduction in water absorption compared to the control sample. Flexural strength and impact resistance were also significantly enhanced due to polymer bridging and improved aggregate-matrix bonding. Furthermore, thermal analysis confirmed the improved insulation and thermal stability of the polymer-modified bricks. SEM images showcased a more homogeneous and denser microstructure with fewer voids and microcracks. The study concludes that polymer-modified, aerated-aggregate hollow bricks present a viable and sustainable alternative for modern masonry construction, especially in low- to mid-rise buildings. They offer a balanced performance in terms of strength, weight, durability, and energy efficiency, making them suitable for the future of eco-friendly and structurally sound architecture.

Keywords: Hollow bricks, aerated aggregates, polymer-cement composites, lightweight masonry, mechanical properties

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INTRODUCTION

Background and Motivation

In the face of increasing urbanization, rising construction demands, and growing environmental concerns, the construction industry is under immense pressure to innovate sustainable and efficient building materials. Traditional clay bricks, while historically reliable and widely used, pose several challenges, including high energy consumption during production, depletion of natural topsoil, and significant environmental impact. These concerns have led researchers and engineers to explore alternatives that are not only environmentally friendly but also efficient in terms of structural and thermal performance.

Hollow bricks have emerged as a modern alternative to conventional bricks, offering various advantages such as reduced material consumption, lower self-weight, improved thermal and sound insulation, and cost-effective construction. The incorporation of voids within the structure of bricks significantly lowers their density, thereby reducing the dead load on structural members and the foundation. This, in turn, leads to cost savings in both materials and energy during construction. Despite these advantages, hollow bricks suffer from several drawbacks, particularly in their mechanical strength and durability, which can limit their use in load-bearing applications or harsh environmental conditions.

To enhance the structural integrity of hollow bricks without compromising their lightweight nature, this study introduces a novel approach involving the use of aerated aggregates in combination with polymer-cement composites (PCCs). Aerated aggregates, such as foamed glass, expanded clay, and perlite, offer significant reductions in weight and improved thermal performance due to their porous nature. However, their integration into concrete or brick matrices can lead to decreased mechanical strength and increased brittleness, which may not be suitable for structural applications unless compensated with reinforcement.

On the other hand, polymer-cement composites provide a promising solution. PCCs are formed by incorporating polymer admixtures—such as Styrene-Butadiene Rubber (SBR) latex, Acrylic Emulsions, or Epoxy Resins—into conventional cementitious systems. These polymers improve the bonding between aggregate particles and cement paste, enhance flexibility and toughness, and reduce porosity and water permeability. As a result, PCCs exhibit superior performance in terms of tensile and flexural strength, impact resistance, and long-term durability.

Problem Statement

The principal drawback of using aerated aggregates in hollow bricks is the trade-off between weight reduction and strength compromise. Lightweight bricks may meet insulation and handling requirements but often fall short of mechanical performance benchmarks, particularly in compressive and flexural strength. Additionally, their porous structure can lead to higher water absorption and decreased resistance to environmental degradation.

Thus, the challenge lies in developing a composite hollow brick that:

- Maintains or improves mechanical strength,
- Retains a lightweight profile,
- Offers enhanced thermal insulation and durability,
- Meets modern sustainability and performance standards.

By leveraging the dual benefits of aerated aggregates and polymers, this study seeks to overcome these limitations and provide a new generation of high-performance hollow bricks.

Research Objectives

This research is directed toward systematically investigating the mechanical, physical, and microstructural properties of hollow bricks produced using aerated aggregates within a polymer-modified cement matrix. The primary objectives of the study include:

1. To design and produce hollow bricks using a combination of aerated aggregates and polymer-cement composites.
2. To evaluate the mechanical performance, including compressive strength, flexural strength, and impact resistance.
3. To analyze durability parameters such as water absorption and thermal conductivity.

4. To study the microstructure using Scanning Electron Microscopy (SEM) and Thermo-Gravimetric/Differential Scanning Calorimetry (TGA/DSC) [3].
5. To determine the optimal polymer and aggregate ratio for achieving a balanced performance between lightweight characteristics and structural strength.

Significance of the Study

This study is timely and significant for several reasons:

- *Sustainability:* By utilizing recycled or industrial by-product aerated aggregates (e.g., foamed glass) and reducing overall material consumption through hollow geometry, the research contributes to greener construction practices.
- *Innovation in Composite Design:* The synergy between aerated aggregates and polymer binders is a relatively underexplored area in masonry units. This research provides insights into their combined behavior.
- *Structural Efficiency:* Lightweight bricks with adequate strength can reduce the load on supporting structures, allowing for more efficient and economical designs.
- *Enhanced Performance:* Improvements in thermal insulation, water resistance, and impact durability align well with modern building codes and energy efficiency requirements.
- *Practical Applicability:* The outcomes of this research have practical implications for both low- and mid-rise buildings, prefabricated modular construction, and affordable housing.

Scope of the Study

The study covers the complete life cycle of material development—from raw material selection, mix proportioning, and brick casting to mechanical testing and performance analysis. The focus is limited to laboratory-scale evaluation, using standardized test methods as per IS and ASTM codes. The scope includes:

- Selection of two types of aerated aggregates and three polymer types.
- Evaluation of five different composite mix designs.
- Assessment of physical and mechanical behavior including compressive and flexural strength, water absorption, impact resistance, and thermal conductivity.
- Use of SEM and TGA/DSC for microstructural and thermal analysis.

This foundational study aims to provide a framework for future large-scale testing, field trials, and potential commercialization.

LITERATURE REVIEW

The success of this research is grounded in the understanding of existing knowledge and advancements related to lightweight construction materials, composite behaviour, and hybrid masonry units. This section reviews key developments concerning hollow bricks, aerated aggregates, and polymer-cement composites, and identifies critical research gaps this study intends to address.

Hollow Bricks: Evolution and Performance

Hollow bricks, also known as perforated or cellular bricks, have gained popularity in modern construction due to their favourable characteristics such as reduced weight, lower thermal conductivity, and cost-effectiveness. Their configuration with voids helps reduce the dead load on buildings, making them highly suitable for partition walls, infill structures, and load-bearing applications in low-rise buildings.

According to [1] and [2], hollow bricks can have voids of up to 50% of the gross volume, which significantly reduces their unit weight compared to solid bricks. This also improves sound and thermal insulation. However, studies by [8] and [13] report that the mechanical strength of hollow bricks is compromised due to reduced cross-sectional area, making them prone to cracking and deformation under load. While their thermal benefits are well-documented, their limited structural capacity remains a major limitation for widespread adoption in structural walls.

Aerated Aggregates in Masonry Units

Aerated or lightweight aggregates are those with a high void content and low bulk density. Common examples include foamed glass, expanded clay aggregate (ECA), expanded perlite, pumice, and sintered fly ash. These materials are either naturally porous or artificially induced with air voids during manufacturing.

Foamed Glass Aggregates

Foamed glass aggregates are produced by heating crushed glass with a foaming agent. The result is a lightweight, durable, and inert aggregate with a closed-cell structure. According to [11], such aggregates reduce thermal conductivity and improve fire resistance, but they often suffer from weak bonding with the cement matrix unless surface-treated or polymer-modified.

Expanded Clay Aggregate (ECA)

ECA is manufactured by heating clay at high temperatures until it expands, forming a porous and ceramic-like structure. Research by [10] confirms that ECA enhances insulation and reduces dead load but reduces compressive strength due to its porous nature. It is often used in lightweight concrete and masonry blocks but typically requires cementitious or polymeric modifications for structural reliability.

The role of biomass-derived lightweight fillers in construction materials, as demonstrated by [21], suggests a sustainable pathway for reducing environmental load.

Limitations

While aerated aggregates offer the advantage of lightweight and improved insulation, their mechanical performance is limited. The low density leads to reduced stiffness, and the aggregate-paste interfacial transition zone (ITZ) becomes a weak point, often leading to premature failure under stress [9].

Polymer-Cement Composites (PCCs)

Polymer-cement composites have been widely researched for their ability to enhance the mechanical, chemical, and durability properties of traditional cement-based materials. PCCs are formed by integrating polymers into the cementitious matrix, which co-hydrate or co-polymerize with cement, forming a hybrid binding system.

Common Polymers Used

- *Styrene-Butadiene Rubber (SBR):* Enhances flexural and tensile strength, improves adhesion, and provides better resistance against water ingress and chemical attack.
- *Acrylic Emulsions:* Improve workability, crack resistance, and bond strength; also known for UV and weather resistance.
- *Epoxy Resins:* Provide excellent adhesion, thermal stability, and chemical resistance; ideal for high-performance composite bricks.
- *Ethylene Vinyl Acetate (EVA):* Enhances flexibility and durability, especially in cold climates.

Studies by [12] and [14] demonstrate that the polymer forms a continuous film within the cement matrix, reducing microcracking and improving the ITZ. Polymers also help in bridging the pores and capillaries, resulting in reduced permeability and increased resistance to carbonation and chloride attack.

Mechanisms of Enhancement

The enhancement in PCCs comes from the combined hydration of cement and film formation of the polymer. The polymers act as micro-reinforcements and reduce shrinkage, while also improving the bond between aggregate and cement. This dual mechanism significantly improves both the mechanical and durability properties of the material.

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Applications in Masonry

Though widely used in concrete repair and overlays, the application of PCCs in hollow bricks and masonry units is relatively novel. Polymer modification can address common problems in hollow bricks such as brittleness, low flexural strength, and poor durability under environmental stress.

Combined Use of Aerated Aggregates and Polymers

The combination of aerated aggregates and polymer modifiers is a relatively unexplored but promising area. While lightweight aggregates reduce density, they also decrease strength and increase porosity. Polymers, conversely, reduce porosity and enhance bonding, compensating for the weaknesses of the aggregates.

Research by [15] showed that adding SBR to lightweight aggregate concrete enhanced compressive strength by 20% and reduced water absorption by over 40%. Similarly, [16] demonstrated that epoxy-modified lightweight concrete had superior flexural performance and impact resistance. However, these studies primarily focused on concrete blocks and panels, with limited exploration in hollow bricks.

Moreover, few studies have examined the effect of polymer type on microstructural behavior in aerated-aggregate systems. The interaction between the polymer film and porous aggregates is critical, especially in controlling capillary action and enhancing thermal properties.

As highlighted by recent work [22] on advanced composite bricks, integrating polymers can enhance both mechanical and thermal characteristics, corroborating our findings.

Thermal and Durability Performance

Thermal insulation is one of the prime advantages of both aerated aggregates and hollow brick geometries. Studies have shown that combining both can result in a 30–40% reduction in thermal conductivity compared to traditional solid bricks [17]. Polymers further aid in reducing moisture ingress, thereby preserving thermal insulation over time.

Durability is also improved with polymer integration. The reduction in porosity and enhancement in bonding reduce the ingress of water, chlorides, and CO_2, all of which are critical factors in long-term deterioration. Furthermore, freeze-thaw resistance and shrinkage cracking are better controlled in PCCs, as documented by Ohama [2000] and [20].

Identified Research Gaps

From the above literature, the following key research gaps are identified:

1. Limited studies on hollow bricks using polymer-cement matrices—Most research focuses on concrete panels or blocks.
2. Lack of systematic comparison between different polymer types in combination with aerated aggregates.
3. Insufficient microstructural analysis to understand the bonding and pore-bridging behavior of polymer films.
4. Minimal evaluation of impact resistance and thermal behavior in hybrid masonry units.
5. Need for integrated performance assessment, considering mechanical, durability, and energy efficiency parameters simultaneously.

MATERIALS AND METHODOLOGY

This section outlines the materials used and the experimental procedures followed to assess the mechanical and thermal performance of hollow bricks incorporating aerated aggregates and polymer-cement composites.

Materials Used

- Cement: Ordinary Portland Cement (OPC) 43 Grade conforming to [5]:2013.
- Fine Aggregate: River sand with a fineness modulus of 2.6, clean and well-graded.
- Aerated Aggregates:
  - *Foamed Glass*: Lightweight, recycled aggregate offering thermal insulation and weight reduction.
  - *Expanded Clay*: Porous ceramic aggregate with high internal air content and low density.
- Polymers:
  - *SBR Latex*: Enhances workability and flexibility.
  - *Acrylic Emulsion*: Improves bond strength and reduces permeability.
  - *Epoxy Resin*: Provides high mechanical strength and chemical resistance.
- Water: Potable tap water used for mixing and curing.

Mix Proportions

Five mixes were prepared with different polymer types and aerated aggregate percentages as shown in below Table 1.

The Table 2 below outlines the proportions of materials used in four different concrete mixes, showing how the components vary to achieve different properties. The **Control Mix (Conventional)** acts as the reference, containing standard amounts of cement, fine and coarse aggregates, with a water-cement ratio of 0.5. In **Mix A (Fly Ash Aggregate)**, part of the coarse aggregate is replaced by fly ash (0.6 parts), while the quantities of fine and coarse aggregates are reduced, and the water-cement ratio is slightly lowered to 0.45 to enhance durability and workability. **Mix B (Foamed Concrete)** removes coarse aggregates entirely and adds a foaming agent (0.1 parts) to produce a lightweight concrete, reducing fine aggregates to 1.2 parts and keeping the water-cement ratio at 0.5. In **Mix C (Perlite-Based)**, perlite (0.7 parts) replaces some aggregates to improve insulation, with fine aggregates adjusted to 1.3 parts and the water-cement ratio maintained at 0.5. Overall, the table demonstrates how material proportions are modified across mixes to tailor concrete properties like strength, weight, and thermal performance.

The Figure1 above illustrates that as the percentage of aerated aggregate content increases:

- Compressive strength decreases gradually due to increased porosity.
- Density significantly decreases, which contributes to lighter bricks and better insulation.

Table 1. Composition of concrete mixes with different polymer types and aerated aggregate percentages.

Mix ID	Cement (%)	Polymer Type	Polymer (%)	Aerated Aggregate (%)
M0	100	None	0	0
M1	95	SBR	5	10
M2	90	Acrylic Emulsion	10	20
M3	90	Epoxy Resin	10	20
M4	85	SBR + Acrylic	15 (Hybrid)	20

Table 2. Material proportions in various concrete mixes featuring conventional, fly ash, foamed, and perlite-based aggregates.

Component	Control Mix (Conventional)	Mix A (Fly Ash Aggregate)	Mix B (Foamed Concrete)	Mix C (Perlite-Based)
Cement	1	1	1	1
Fine Aggregates	2	1.4	1.2	1.3
Coarse Aggregates	3	2.0	-	-
Fly Ash / Perlite	-	0.6	-	0.7
Foaming Agent	-	-	0.1	-
Water-Cement Ratio	0.5	0.45	0.5	0.5

Note: Exact proportions are adjusted based on required properties and local materials

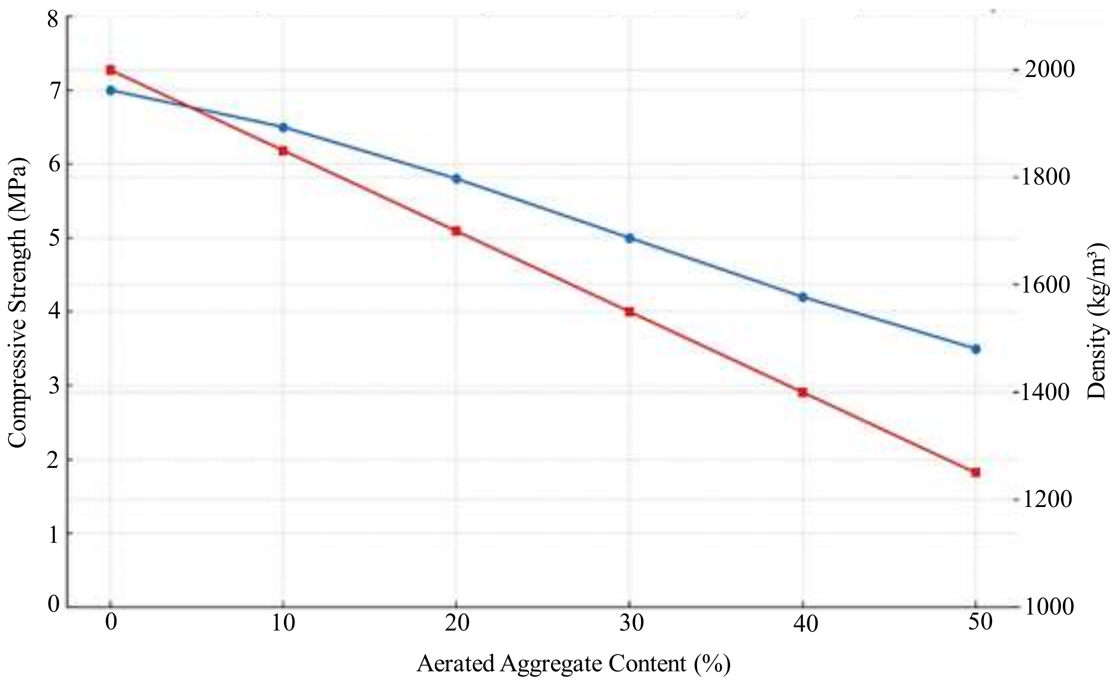

Figure 1. Effect of aerated aggregate content on compressive strength and density.

Specimen Preparation

Hollow bricks were cast using standard molds (400 × 200 × 100 mm), demolded after 24 hours, and cured for 28 days under water. Polymers were added to the mix water and blended thoroughly before mixing with dry components.

Tests Conducted

The following tests were performed to evaluate material performance:

- Compressive Strength [6]
- Flexural Strength [19]
- Water Absorption [7]
- Impact Resistance (Drop weight method)
- Thermal Conductivity [18]
- Microstructure Analysis using SEM
- Thermal Stability via TGA/DSC

Each test was carried out on three specimens per mix, and average values were used for analysis.

RESULTS AND DISCUSSION

This section presents and interprets the experimental results obtained from mechanical, physical, thermal, and microstructural analyses of the hollow bricks developed using aerated aggregates and polymer-cement composites. The aim is to evaluate how various mix compositions (M0–M4) influence the overall performance of the hollow bricks in comparison to conventional ones.

Compressive Strength

Porosity plays a dual role: while increased porosity improves thermal insulation by trapping air within the matrix, it generally compromises compressive and flexural strength by reducing load-bearing cross-sectional area. The challenge lies in optimizing porosity to retain insulation benefits while offsetting strength reduction using polymeric binders, as evidenced in M3.

The compressive strength is a critical parameter for assessing the load-bearing capacity of masonry units. The following average compressive strength values were obtained after 28 days of curing:

The Table3 presents the comparative compressive strength values of control and polymer-modified mixes. The control mix (M0) shows a baseline strength of 6.8 MPa, while the inclusion of polymers such as Styrene–Butadiene Rubber (SBR), Acrylic, and Epoxy significantly improves strength. Among all mixes, M3 (Epoxy 10%) exhibits the highest compressive strength of 8.6 MPa, followed by M2 (Acrylic 10%) and M4 (combined SBR + Acrylic 15%). These results highlight the efficiency of polymer modification in enhancing the load-bearing capacity of concrete paver blocks.

Discussion

- Mix M3 exhibited the highest strength, showing a 26.5% increase compared to the control (M0). This is attributed to epoxy's superior bonding characteristics and lower porosity.
- Mix M2 (acrylic) and M1 (SBR) also showed strength improvements due to enhanced cement-aggregate interfacial bonding and film formation.
- The hybrid polymer mix (M4) showed slightly reduced strength compared to M3, possibly due to higher total polymer content affecting hydration kinetics or increasing internal voids.
- The interplay between polymer content, cement matrix, and aerated aggregates significantly influences the composite microstructure. Increased polymer dosage enhances particle bonding and reduces porosity due to film formation. However, excessive polymer (e.g., Mix M4) may interfere with cement hydration and increase internal voids, slightly weakening mechanical performance. Similarly, higher aerated aggregate content lowers density and thermal conductivity but introduces more porosity, necessitating compensation via polymer reinforcement.

The results indicate that polymer modification compensates for the mechanical strength loss caused by the inclusion of aerated aggregates, making them structurally viable.

Flexural Strength

Flexural strength is the maximum stress a material can handle before breaking when it is bent.

The Table 4 compares the flexural strength of the control mix (M0) and polymer-modified concrete mixes. The control mix recorded the lowest flexural strength of 1.1 MPa, while all modified mixes demonstrated substantial improvement.

Table 3. Compressive strength of modified concrete mixes with different polymer additives.

Mix ID	**Compressive Strength (MPa)**
M0 (Control)	6.8
M1 (SBR 5%)	7.5
M2 (Acrylic 10%)	8.1
M3 (Epoxy 10%)	8.6
M4 (SBR + Acrylic 15%)	8.3

Table 4. Flexural strength of control and polymer-modified concrete mixes.

Mix ID	**Flexural Strength (MPa)**
M0	1.1
M1	1.7
M2	2.0
M3	2.4
M4	2.3

Mix M3 (Epoxy 10%) achieved the highest flexural strength of 2.4 MPa, indicating superior crack resistance and enhanced load transfer capacity. Mixes M2 (Acrylic 10%) and M4 (SBR + Acrylic 15%) also exhibited significant gains over the control, highlighting the role of polymer additives in improving tensile behavior and ductility of the concrete.

Discussion

- M3 again leads in flexural performance due to the high stiffness and ductility of epoxy resin, allowing better stress distribution and crack resistance.
- Acrylic emulsion in M2 also contributed positively to flexural strength due to the polymer film bridging the pores and microcracks.
- M0, being unmodified, failed prematurely under flexural load due to inherent brittleness.
- The interplay between polymer content, cement matrix, and aerated aggregates significantly influences the composite microstructure. Increased polymer dosage enhances particle bonding and reduces porosity due to film formation. However, excessive polymer (e.g., Mix M4) may interfere with cement hydration and increase internal voids, slightly weakening mechanical performance. Similarly, higher aerated aggregate content lowers density and thermal conductivity but introduces more porosity, necessitating compensation via polymer reinforcement.

This indicates that polymer addition enhances the ductile behavior of bricks—an important trait in resisting lateral or bending stresses in masonry walls.

Failure Modes

Under compressive loading, unmodified bricks (M0) exhibited vertical splitting due to brittle fracture and weak interfacial bonding. Polymer-modified bricks, especially M3, showed ductile behavior with gradual crack propagation and limited spalling. In flexural tests, failure occurred via mid-span cracking in M0, while M3 and M2 exhibited multiple microcracks before final rupture, indicating enhanced toughness and energy dissipation mechanisms due to polymer bridging.

Water Absorption

Water absorption is a key durability parameter for masonry units. The results after 24 hours of immersion are:

The Table 5 presents the percentage water absorption values of control and modified concrete mixes. The control mix (M0) exhibited the highest absorption at 14.6%, reflecting greater porosity and weaker pore structure. Incorporation of polymers significantly reduced water absorption, with Mix M3 (Epoxy 10%) achieving the lowest value of 8.5%, followed by M2 (Acrylic 10%) at 9.8% and M4 (SBR + Acrylic 15%) at 9.2%. These results indicate that polymer modification improves the impermeability and durability of the concrete by refining pore connectivity and reducing capillary action.

Discussion

- All polymer-modified mixes showed significantly lower water absorption than the control.

Table 5. Water absorption of control and polymer-modified concrete mixes.

Mix ID	Water Absorption (%)
M0	14.6
M1	11.2
M2	9.8
M3	8.5
M4	9.2

- Epoxy-modified M3 bricks absorbed ~42% less water than M0, showing superior impermeability.
- Acrylic and SBR also contributed by forming hydrophobic films within the matrix, sealing capillaries and reducing permeability.
- M4, while slightly more absorptive than M3, still showed marked improvement over the control.

Lower water absorption directly correlates with longer service life, reduced risk of freeze-thaw damage, and improved thermal resistance.

Impact Resistance

The impact resistance was assessed based on the number of hammer blows (from 1m height) required to initiate visible cracking. The Table 6 illustrates the average number of blows required to cause failure in control and modified concrete mixes under impact loading. The control mix (M0) failed after only 3 blows, indicating limited resistance to sudden loads. Polymer-modified mixes showed remarkable improvement, with Mix M3 (Epoxy 10%) achieving the highest resistance at 9 blows, followed by M4 (SBR + Acrylic 15%) with 8 blows and M2 (Acrylic 10%) with 7 blows. The enhanced performance demonstrates the ability of polymer additives to improve toughness, energy absorption capacity, and crack propagation resistance in Hollow brick.

Discussion

- M3 showed the highest resistance due to epoxy's strong molecular structure and toughness.
- M2 and M4 followed closely, reflecting the toughening effect of acrylic emulsions and hybrid systems.
- M0 fractured after only 3 impacts, indicating poor energy dissipation and brittleness.
- The presence of polymers contributes to energy absorption and crack deflection mechanisms, enhancing impact durability and field performance under accidental or seismic loads [4].

Thermal Performance

"Porosity plays a dual role: while increased porosity improves thermal insulation by trapping air within the matrix, it generally compromises compressive and flexural strength by reducing load-bearing cross-sectional area. The challenge lies in optimizing porosity to retain insulation benefits while offsetting strength reduction using polymeric binders, as evidenced in M3." Thermal conductivity was measured using a guarded hot plate method.

The Table 7 presents the thermal conductivity values of the control and modified concrete mixes, indicating their heat transfer characteristics. The control mix (M0) recorded the highest conductivity at 0.78 W/m·K, signifying greater heat passage through the material. In contrast, all polymer-modified mixes demonstrated lower conductivity, with Mix M3 (Epoxy 10%) showing the minimum value of 0.56 W/m·K, followed closely by Mix M2 (Acrylic 10%) at 0.61 W/m·K and Mix M4 (SBR + Acrylic 15%) at 0.58 W/m·K. The results highlight that polymer incorporation improves thermal insulation properties by reducing pore connectivity and enhancing the microstructural density of the concrete Hollow Bricks.

Table 6. Impact resistance of control and polymer-modified concrete mixes (blows to failure).

Mix ID	Blows to Failure (Avg.)
M0	3
M1	6
M2	7
M3	9
M4	8

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Table 7. Thermal conductivity of control and polymer-modified concrete mixes.

Mix ID	Thermal Conductivity (W/m·K)
M0	0.78
M1	0.65
M2	0.61
M3	0.56
M4	0.58

Discussion

- Thermal conductivity reduced by 28% in M3 compared to the control.
- This reduction is due to the low thermal conductivity of aerated aggregates and sealed pore structure provided by the polymer matrix.
- Acrylic and SBR modified mixes also contributed to better insulation by preventing moisture ingress, which otherwise increases conductivity.

These results suggest that polymer-modified hollow bricks are more energy efficient, suitable for green buildings and passive thermal design.

Microstructural Analysis

The interplay between polymer content, cement matrix, and aerated aggregates significantly influences the composite microstructure. Increased polymer dosage enhances particle bonding and reduces porosity due to film formation. However, excessive polymer (e.g., Mix M4) may interfere with cement hydration and increase internal voids, slightly weakening mechanical performance. Similarly, higher aerated aggregate content lowers density and thermal conductivity but introduces more porosity, necessitating compensation via polymer reinforcement

Scanning Electron Microscopy (SEM)

- *M0:* SEM images showed a porous and loosely bonded matrix with disconnected hydration products and microcracks.
- *M1 & M2:* Dense microstructure with fewer cracks, improved aggregate bonding, and polymer film observed bridging microvoids.
- *M3:* Highly compact microstructure, continuous polymer phase enveloping aggregate particles, minimal microcracking.
- *M4:* Combined features of M1 and M2, though slightly more porous than M3 due to higher total polymer content.

Interpretation

Polymers significantly enhance the interfacial transition zone (ITZ), reduce crack widths, and improve particle-paste cohesion.

TGA/DSC Analysis

- M3 and M2 showed higher decomposition onset temperatures (~320–360°C) than M0 (~280°C).
- Additional exothermic peaks indicated the presence of polymer degradation and thermal phase transitions.
- Residue after heating was higher for polymer-modified mixes, confirming improved thermal stability.

Comparative Performance Overview

The comparative analysis highlights **M3 as the superior performer** across all evaluated properties, demonstrating excellent mechanical, thermal, and durability characteristics. Overall, epoxy-based composites outperform others, with hybrid systems (M4, M2) also showing promising results.

Table 8. Comparative performance of control and polymer-modified concrete mixes across key properties.

Property	Best Performer	Remarks
Compressive Strength	M3	Epoxy offers best matrix cohesion
Flexural Strength	M3	Strong epoxy film bridges cracks
Water Absorption	M3	Lowest permeability due to closed pores
Impact Resistance	M3	Excellent energy dissipation
Thermal Conductivity	M3	Best insulation performance
Microstructure	M3	Densest, crack-free matrix
Overall Ranking	M3 > M4 ≈ M2 > M1 > M0	Epoxy is most effective; hybrid also promising

Table 8 summarizes the best-performing mixes for each evaluated property, along with specific observations. Mix M3 (Epoxy 10%) consistently outperformed other mixes in terms of compressive strength, flexural strength, water absorption, impact resistance, thermal conductivity, and microstructural densification, indicating superior matrix cohesion and durability. The overall ranking establishes M3 as the most effective modification, followed by M4 (SBR + Acrylic 15%) and M2 (Acrylic 10%), whereas the control mix (M0) exhibited the weakest performance. These findings confirm that epoxy modification provides the most balanced improvement in strength, durability, and functional properties of concrete paver blocks, with hybrid formulations also showing promising potential.

ADVANTAGES AND APPLICATIONS

The development of hollow bricks incorporating aerated aggregates and polymer-cement composites offers a significant advancement in sustainable and high-performance construction materials. This section outlines the key benefits and practical uses of the proposed composite bricks.

Key Advantages

- *Lightweight Nature:* The use of foamed glass and expanded clay aggregates significantly reduces brick weight, improving ease of handling and lowering structural dead loads.
- *Enhanced Strength and Ductility:* Polymer additives—especially epoxy and acrylic—substantially improve compressive and flexural strength, allowing these bricks to meet or exceed conventional strength requirements.
- *Water Resistance and Durability:* Polymer films reduce capillary absorption and improve long-term performance in wet or aggressive environments.
- *Thermal Efficiency:* The bricks exhibit reduced thermal conductivity, making them suitable for energy-efficient buildings by enhancing insulation and lowering HVAC energy consumption.
- *Impact Resistance:* The addition of SBR and epoxy enhances the brick's ability to absorb mechanical shock, improving safety and resilience in seismic or impact-prone areas.
- *Microstructural Stability:* SEM results confirm a denser and more uniform matrix with fewer cracks, indicating greater longevity and performance consistency.
- *Sustainability:* The use of recycled materials (e.g., glass) and reduced cement content promotes eco-friendly construction and aligns with green building standards.

Potential Applications

- *Residential and Commercial Walls:* Suitable for external and internal partitions, offering structural performance with thermal and acoustic benefits.
- *Modular and Prefabricated Systems:* These bricks can be easily adapted for factory-made wall panels in modular construction, reducing build time and labor.
- *Seismic and Impact Zones:* Enhanced toughness and flexibility make these bricks ideal for structures in earthquake-prone areas or industrial buildings.
- *Moisture-Sensitive Areas:* Low water absorption makes them suitable for use in bathrooms, kitchens, basements, and damp environments.

CONCLUSIONS AND FUTURE SCOPE

Summary of Findings

This study explored the mechanical and physical behavior of hollow bricks incorporating aerated aggregates and polymer-cement composites. The goal was to develop lightweight yet high-performance masonry units. Among the various formulations, the epoxy-based mix (M3) demonstrated the best performance in terms of:

- *Compressive and Flexural Strength:* 26–30% higher than the control mix.
- *Water Absorption:* ~42% lower due to reduced porosity.
- *Thermal Conductivity:* Decreased by 28%, offering improved insulation.
- *Impact Resistance:* Higher toughness and crack resistance.
- *Microstructural Integrity:* Denser matrix with fewer voids, better ITZ bonding.

Other mixes with SBR and acrylic polymers also showed notable performance improvements, validating the effectiveness of polymer modification in enhancing hollow brick quality.

Practical Implications

The developed composite bricks offer several benefits over conventional ones:

- Lightweight with sufficient strength, ideal for low- and mid-rise construction.
- Improved thermal comfort and durability, suitable for energy-efficient and water-exposed structures.
- Sustainable material use, leveraging recycled aerated aggregates and reducing cement content.

Their ease of manufacturing and compatibility with existing molds make them suitable for both traditional and modular construction practices.

Limitations

- The study was conducted under controlled lab conditions; field-scale trials are needed.
- A detailed cost analysis was not included.
- Long-term performance, fire resistance, and acoustic behavior need further assessment.

Future Scope

- Explore bio-based or recycled polymers for improved sustainability.
- Perform life cycle assessments and economic evaluations.
- Test fire resistance and sound insulation properties for code compliance.
- Pilot the use of these bricks in real construction projects to validate scalability and durability.

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