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Influence of Material Composition on the Strength and Durability of Hollow Bricks: A State-of-the-Art Review and Sustainability Perspective

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Abstract

Hollow bricks have gained increasing attention as sustainable masonry units due to their reduced material consumption, lower self-weight, and improved thermal efficiency compared to conventional solid bricks. However, their structural applicability and long-term performance are strongly governed by material composition, which influences strength development, durability, and environmental impact. This state-of-the-art review critically examines the influence of binder systems, aggregate characteristics, supplementary cementitious materials, and fiber reinforcement on the mechanical and durability performance of hollow bricks. A systematic literature review was conducted using Scopus and Web of Science databases, focusing on peer-reviewed studies published between 2005 and 2025. The review synthesizes findings on compressive, tensile, and flexural strength, along with key durability indicators such as water absorption, efflorescence, chemical resistance, and weathering behavior. Results from the literature indicate that the incorporation of industrial by-products such as fly ash, ground granulated blast furnace slag, rice husk ash, and silica fume significantly enhances long-term strength and durability through pore refinement and improved microstructural densification. Fiber reinforcement, particularly steel and polypropylene fibers, further improves crack control and post-cracking performance, extending the structural potential of hollow bricks. In addition, the review highlights the role of material optimization in reducing embodied carbon, supported by life cycle assessment studies and alignment with relevant Sustainable Development Goals. The paper concludes by identifying critical research gaps related to long-term durability, service-life-based sustainability assessment, and standardization, and proposes future research directions for developing high-performance, durable, and environmentally responsible hollow brick systems for modern construction.

Keywords: Durability Performance, Hollow Bricks, Life Cycle Assessment, Material Composition, Strength Development, Sustainable Masonry Materials.

Introduction

Hollow bricks have emerged as sustainable masonry units due to their lower material consumption, reduced self-weight, and improved thermal performance compared to conventional solid bricks. However, their structural efficiency and long-term durability are strongly influenced by material composition and microstructural characteristics. This state-of-the-art review critically examines the effects of binder systems, aggregate properties, supplementary cementitious materials, and fiber reinforcement on the mechanical and durability performance of hollow bricks. Based on peer-reviewed studies indexed in Scopus and Web of Science (2005–2025), the review evaluates strength properties, water absorption, efflorescence, chemical resistance, and weathering behaviour associated with sustainable hollow brick systems. Literature findings indicate that industrial by-products such as fly ash, GGBS, rice husk ash, and silica fume enhance the long-term strength and durability of hollow bricks through pore refinement and microstructural densification. Steel and polypropylene fibers improve crack resistance and post-cracking behavior, thereby enhancing structural performance. The review also highlights the role of material optimization in reducing embodied carbon through life cycle assessment approaches aligned with Sustainable Development Goals. Furthermore, key research gaps related to long-term durability, sustainability assessment, and standardization are identified. The construction industry is also one of the biggest energy users of the natural resources as well as one of the biggest producers of greenhouse gases in the world mainly because of the widespread use of energy-intensive

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materials, including cement and fired clay products (1, 2). In the case of masonry construction which is one of the building methods that continue to dominate in most parts of the world, the construction depends on traditional solid bricks with high material consumption, high embodied energy, and low thermal value (3). The progressive development of the alternative masonry units that can minimize the material consumption and yet provide the adequate structural and durability performance has been in reaction to the rise in environmental issues and the growing focus on sustainable construction practices.

The hollow bricks have proven to be a viable option in this regard because of their low density, material efficiency and better thermal insulation than the solid masonry unit (4, 5). The hollow bricks have internal voids and thus lower self-weight and better energy performance without necessarily changing the way the construction is done, so they suit both low-rise and medium-rise buildings (6). Nonetheless, void's introduction also changes the load-transfer processes and stress redistribution, which further amplifies the role of material composition in the regulation of the mechanical strength and long-term performance (7).

Geometric arrangement is not the only factor that determines the performance of hollow bricks; the type of binder, aggregate nature, and the use of additional materials make a significant impact on the performance of hollow bricks (8). The hydration and carbonation reactions are regulated by binder chemistry, whereas the particle packing and stress transfer in the matrix is determined by the aggregate grading and morphology (9). Recently, considerable research on the application of industrial by-products as partial substitutes of ordinary cement in hollow bricks has been conducted on fly ash, ground granulated blast furnace slag (GGBS), rice husk ash, and silica fume (10–12). It has been demonstrated that these materials can alter the structure of pores, decrease their permeability, and increase their long-term strength by means of pozzolanic and latent hydraulic reactions (13).

The durability performance of hollow bricks is intrinsically governed by their microstructural characteristics, particularly pore size distribution, pore connectivity, and the quality of the interfacial transition zone (ITZ). A refined pore structure reduces capillary suction and permeability, thereby limiting water ingress, ion transport, and associated degradation mechanisms such as efflorescence and chemical attack (14, 15). In addition, a dense and well-developed ITZ enhances stress transfer between the binder and aggregates while minimizing preferential pathways for moisture and chloride penetration (16). The incorporation of supplementary cementitious materials further promotes secondary C–S–H formation, leading to pore refinement and reduced connectivity, which significantly improves resis-tance to environmental deterioration. There-fore, a clear understanding of the relationship between material composition, microstructural evolution, and durability mechanisms is essential for predicting long-term performance of hollow brick systems.

Simultaneously, sustainability has become more significant, and life cycle assessment (LCA) became one of the essential methods of measuring the environmental benefits of alternative masonry materials (17, 18). Maximizing the hollow brick composition with the help of industrial by-products is not only better performance but also helps to reduce embodied carbon levels as well as resource use, which are the global Sustainable Development Goals regarding sustainable infra-structure and climate action (19). Mechanical performance, durability and sustainability, which are interconnected and should be checked in the same assessment framework, are not yet looked at in their wholesome.

To this end, this study presents a state-of-the-art review with an integrated focus on material composition, microstructural mechanisms, durabi-lity performance, and sustainability assessment of hollow bricks.

The review is a critical synthesis of high quality experimental and analytical research that has been published in Scopus- and Web of Science indexed journals, binder systems, aggregate characteristics, supplementary cementitious materials, and fiber reinforcement.

The purposes of this review are to

(a) Clarify the principal processes in the strength and durability,
(b) Establish the significant material-performance correlation,
(c) Evaluate the implications of sustainability with the help of LCA-based evidence, and

(d) Point out current gaps in research and future of development of high-performance, durable, and environmentally responsible hollow bricks systems.

This review distinctly differentiates itself from existing studies by adopting an integrated approach that simultaneously considers material composition, microstructural evolution, durability mechanisms, and life cycle sustainability of hollow bricks. Unlike conventional reviews that primarily focus on individual aspects such as strength or environmental impact, the present study establishes explicit interrelationships between pore structure refinement, interfacial transition zone (ITZ) characteristics, and durability indicators including water absorption, permeability, and chemical resistance. Furthermore, the incorporation of Life Cycle Assessment (LCA) provides a quantitative evaluation of embodied carbon and energy reduction, enabling a comprehensive assessment of both engineering performance and environmental sustainability. This combined perspective offers a more holistic understanding of hollow brick systems and supports the development of optimized, high-performance, and sustainable masonry materials.

Methodology

To provide a structured understanding of the interrelationships governing hollow brick performance, a conceptual framework is proposed in this study. The framework establishes a linkage between material composition (binder systems, aggregates, and supplementary cementitious materials), microstructural evolution (pore structure, pore connectivity, and interfacial transition zone characteristics), and resulting performance parameters including mechanical strength, durability, and sustainability. Material composition influences hydration and pozzolanic reactions, which govern microstructural development, and in turn control strength and resistance to environmental degradation. These performance characteristics ultimately determine the service life and environmental impact of hollow brick systems. The proposed framework is further elaborated in the subsequent sections to provide a comprehensive and integrated understanding of hollow brick behavior.

The review was done in a systematic and clear methodology to achieve full coverage, reproducibility and scientific rigor. The used strategy is in line with the best practices suggested to write high-quality review articles in the construction materials research and complies with the principles of the PRISMA framework of systematic reviews and meta-analyses (20, 21).

Literature Search Strategy

The Scopus database and the Web of Science (WoS) databases were chosen as superior sources of high-impact, peer-reviewed journals on the topics of construction materials, masonry systems, and sustainable infrastructure, since these databases cover a significant portion of the subject (22). The search duration was between the year 2005 and 2025, which allowed both historical and recent studies on hollow bricks material to be included.

The search queries were developed based on the combinations of keywords that were searched in the titles, abstracts and author keywords including hollow brick, hollow masonry unit, material composition, compressive strength, durability, supplementary cementitious materials, fiber reinforcement, and life cycle assessment. To narrow the search results and to filter out irrelevant studies, the use of the Boolean operators (AND, OR) was used (23).

Peer-reviewed journal articles published in English were only looked at to guarantee quality and relevancy. The studies had to satisfy the following criteria:

(a) proper reporting of material compounding and production procedure of hollow bricks or masonry units,

(b) quantitative assessment of mechanical characteristics (compressive, tensile, or flexural strength) and/or durability markers (water absorption, chemical resistance, efflorescence, weathering).

(c) Publication in journals indexed in Scopus and Web of science.

Proceedings of conferences, technical reports, theses, and studies that did not contain enough detail of the experiment or were not peer reviewed were not included. Articles that addressed only solid bricks or masonry elements not related to hollow bricks were also excluded to ensure that it was on point (24).

The initial search of the database obtained a high number of publications, which, after the first selection procedure, were filtered with titles and abstracts to exclude those publications that duplicated, and which were not relevant to the research. Potentially relevant articles were then evaluated using full text to verify the eligibility criteria, which had been previously established. The use of this multi-stage screening process reduced selection bias and kept only high-quality and technically relevant studies that were to be synthesized (25).

The relevant data were organized retrieved in the chosen studies, such as material composition, types of binder and aggregates, the additional cementitious material replacement rates, fiber dosage, curing conditions, and the performance results provided. The studies were then grouped into thematic groups by their focus:

(a) strengthening of the mechanical strength,
(b) the performance of an obligation that is durable.
(c) Assessment of environmental and sustainability.

This grouping made it easy to compare various material systems in an organized way, and it also made it possible to determine prevailing trends, performance limits, and knowledge gaps regarding hollow brick materials (26).

To ensure reproducibility and transparency, explicit search strings were formulated using Boolean operators. A representative search query applied in both Scopus and Web of Science databases is as follows: ("hollow brick" OR "hollow masonry unit") AND ("compressive strength" OR "durability") AND ("fly ash" OR "GGBS" OR "silica fume" OR "rice husk ash") AND ("life cycle assessment" OR "sustainability"). Variations of these keywords were also used to capture a broader range of relevant studies. The search was performed within titles, abstracts, and keywords to ensure comprehensive coverage of the literature.

A systematic literature screening and selection methodology was adopted to ensure inclusion of high-quality and relevant studies related to hollow brick materials and performance evaluation. The review process involved identification of records from major scientific databases, followed by duplicate removal, title and abstract screening, and full-text eligibility assessment. The adopted PRISMA-based framework improved the transparency and reliability of the literature selection process. The detailed workflow of the study selection procedure is illustrated in Figure 1.

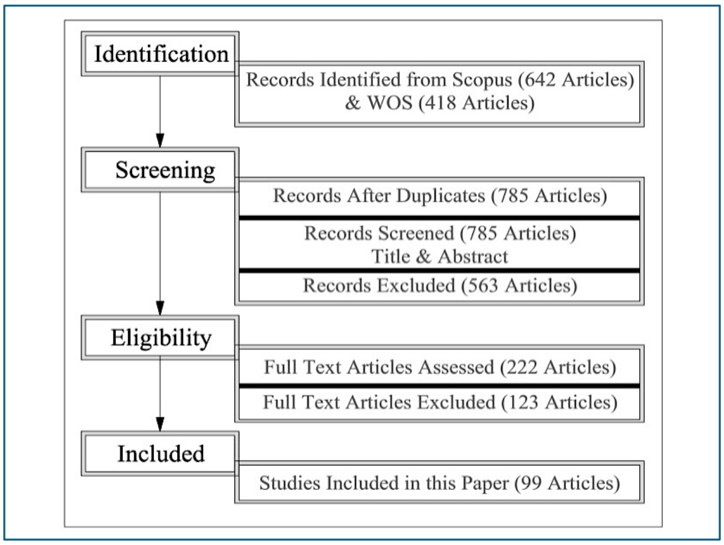

Figure 1: PRISMA-based Flow Diagram for Literature Identification, Screening and Selection

The final inclusion of 99 studies was based on strict quality assessment criteria to ensure reliability and relevance of the synthesized findings. Only peer-reviewed journal articles published in high-impact and indexed journals were considered. Studies were required to provide clear experimental methodology, quantitative performance data (mechanical and/or durability properties), and direct relevance to hollow brick or hollow masonry systems. Articles lacking sufficient experimental validation, incomplete data reporting, or limited relevance to the research objectives were excluded. This quality-based filtering ensured that the final dataset represents robust and scientifically reliable studies suitable for comprehensive analysis.

A systematic classification of the selected literature was performed to identify major research themes associated with hollow brick systems. The reviewed studies were categorized based on mechanical strength, durability performance, and sustainability-oriented investigations including life cycle assessment. The distribution of studies indicates that most existing research primarily focuses on strength behavior, while comparatively fewer studies address long-term durability and environmental assessment. The summarized literature classification and selection details are presented in Table 1.

Table 1: Summary of Literature Selection and Thematic Classification

Category	Description	Number of Studies
Identification	Records retrieved from Scopus and Web of Science databases	1060
Screening	Records screened after duplicate removal	785
Eligibility	Full-text articles assessed for relevance and quality	222
Exclusion	Full-text articles excluded due to scope or data limitations	123
Included	Studies included in qualitative synthesis	99
Strength-focused studies	Studies primarily addressing mechanical strength	~45
Durability-focused studies	Studies focusing on water absorption, chemical attack, weathering	~32
Sustainability/LCA studies	Studies addressing LCA, energy, or environmental impact	~22

Fundamentals of Hollow Brick Materials and Structural Behavior

Hollow bridges are developed masonry elements that are aimed at maximizing the efficiency of the material and meeting the structural and durability criteria. In contrast to solid masonry units, the behaviour of hollow bricks is a coupled effect of material composition and the geometrical configuration, and the combination of these two aspects determines the load transfer, deformation behaviour, and serviceability in the long term (27). An understanding of the basic properties of binder systems, aggregate properties, pore structure and void geometry are thus fundamental in understanding the effects of the advanced material modifications that are discussed in subsequent sections.

Binder Systems Used in Hollow Brick Production

Ordinary Portland cement (OPC) is still the most widely used binder in the hollow bricks manufacturing because it can guarantee the strength development, has great popularity, and can be used with the standard manufacturing processes (8). Mechanical strength of the hollow bricks made of OPC is produced by the hydration reactions resulting in the formation of calcium silicate hydrate (C-S-H) that provides a continuous binding environment to the particles constituting the aggregates (28). Nevertheless, the presence of high content of clinker in the OPC also leads to higher embodied carbon and heat of hydration, which can induce microcracking, and long-term performance is affected negatively in case of improper curing conditions (29).

Microstructural defects related to shrinkage or incomplete hydration can be very important in hollow bricks with the load transfer distributed via thin webs and shells, compressive strength is significantly reduced and permeability enhanced (30). This constraint has encouraged the partial substitution of OPC with additional cementitious materials in the contemporary hollow brick compounds.

Masonry has all along been based on lime-based binders because of their workability and longevity predetermined by the reactions of carbonation (31). Lime in hollow bricks helps in the gradual increase of its strength through forming calcium carbonate that may enhance dimensional stability and resistance to microcracking. Nevertheless, pure lime systems normally have a lower early age strength than OPC based systems, which restricts their independent structural applicability.

To address these shortcomings, mixed binder systems that integrate cement, lime and pozzolanic substances have been extensively embraced. These types of systems bring together the youthful stability of cement hydration in combination with the long-term sustainability of carbonation and pozzolanic responses to create an increased performance balance.

Aggregates are a large proportion of hollow bricks, and they are important in the regulation of mechanical strength, porosity, and dimensional stability. Aggregate grading has a direct effect on the density of the particle packing which controls the void contents and distribution of stress on the brick matrix (32). Aggregates of high grade enhance effective load transfer and minimize stress concentration in the locality enhancing compressive strength and decreasing crack initiation (33).

Due to the exhaustion of natural river sand, the consumption of manufactured sand and quarry dust in masonry products is related to the increased use. Angular particle morphology materials are closed-circuit in nature, increase mechanical interlocking, and can be strengthened when used in the appropriate proportion (34). Nonetheless, too much content in the fines can raise water demand and create negative impacts on workability, and pore structure unless they are managed with great care (35).

Hollow bricks are characterized by a certain number of purpose-made bricks voids that decrease the unit weight and enhance the thermal insulation. Yet, the geometry of the void, namely shape, orientation, and volume fraction, has a highly significant impact on structural behaviour. Compressive loading causes the transfer of stresses mostly using the solid webs and shells; hence these parts play a vital role in failure resistance.

Hollow bricks have porosity at various levels: Hollow geometry generates macro-voids whereas micro-pores are generated on the inside of a binder matrix. Even though macro-voids lead to efficiency of materials, too much micro-porosity leads to higher water uptake and low mechanical strength (36). Consequently, the pore size distribution and connectivity must be controlled to produce a balance between the strength, durability and functional performance.

The performance of binder systems in hollow bricks is fundamentally governed by hydration chemistry. During the hydration of Portland cement, tricalcium silicate (C_3S) and dicalcium silicate (C_2S) react with water to form calcium silicate hydrate (C–S–H) and calcium hydroxide (CH), where C–S–H is the primary phase responsible for strength development. In addition, tricalcium aluminate (C_3A) reacts with sulfate ions to form ettringite during early hydration stages, which influences setting behavior and pore structure development. The presence of calcium hydroxide provides a reactive medium for supplementary cementitious materials such as fly ash and silica fume, which undergo pozzolanic reactions to form additional C–S–H, thereby refining pore structure and enhancing durability. In GGBS-based systems, latent hydraulic reactions contribute to the formation of low-calcium C–S–H, resulting in a denser microstructure and improved resistance to chemical attack. These hydration and secondary reaction mechanisms collectively govern the microstructural evolution, strength development, and long-term durability of hollow brick systems.

Hollow brick geometry significantly influences load-transfer mechanisms, stress distribution, and overall structural efficiency. Variations in shell configuration, web arrangement, and void distribution govern the compressive behavior and cracking response of hollow masonry units. In addition, experimental evaluation using compression testing provides important insights into load-bearing performance and failure characteristics under axial loading conditions. The typical hollow brick geometry and compressive testing arrangement are illustrated in Figure 2.

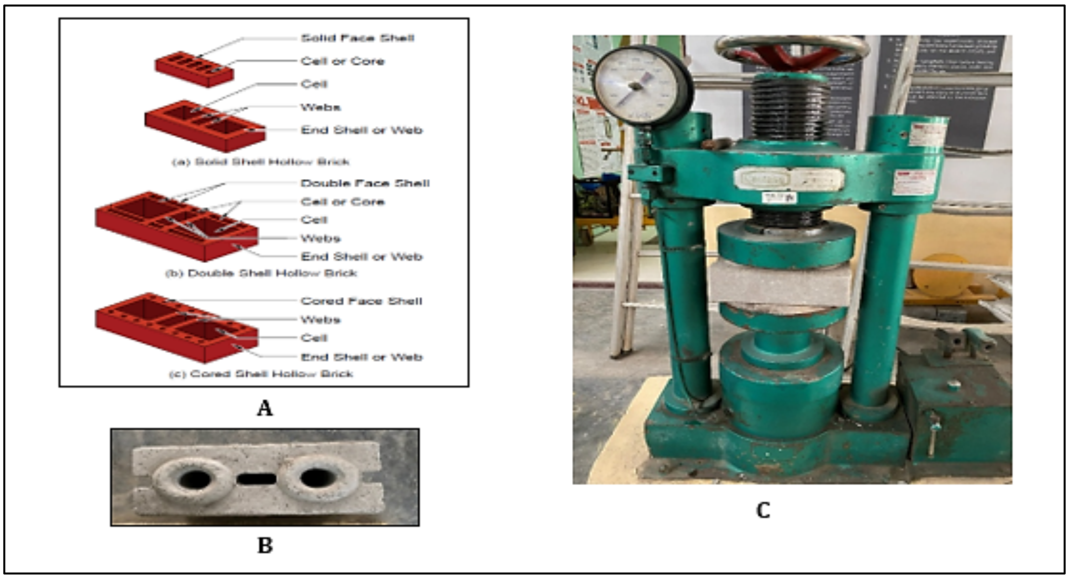

Figure 2: Typical Hollow Brick Geometry and Load Transfer Mechanism. (A) Brick Geometry, (B) Brick, (C) Brick Placed in Compressive Testing Machine

The microstructural aspects including pore connectivity, morphology of hydration products, and the quality of the interfacial transition zone (ITZ) are major factors that have impact on the mechanical and durability performance of hollow bricks (37). Compact and uniform ITZ increases the transfer of stress between the binder and the aggregates, and this leads to an increase in compressive strength and decreased permeability (38).

On the other hand, poor or porous ITZ areas provide favourable channels of moisture entry and crack cracking, which enhances the rate of destruction of structures when exposed to aggressive environments. Fine pozzolanic materials have been depicted to beautify the pore structure and enhance the ITZ density hence increasing the strength and durability (39).

Table 2 summarizes the conventional materials commonly used in hollow brick production along with their functional roles and engineering characteristics. Cement and lime mainly contribute to binding and workability, whereas natural and manufactured sand improve particle packing and load transfer. Quarry dust acts as a fine filler material that enhances matrix densification and cost efficiency. However, each material possesses certain limitations related to sustainability, water demand, or fines control requirements.

Table 2: Conventional Materials Used in Hollow Brick Production and Their Functional Roles

Material	**Function In Hollow Brick**	**Key Properties**	**Advantages**	**Limitations**
Portland cement	Primary binder	High early strength, hydraulic	Predictable performance	High CO_2 footprint
Lime	Secondary binder	Carbonation-based hardening	Improved workability	Low early strength
Natural sand	Fine aggregate	Load transfer, packing	Widely available	Resource depletion
Manufactured sand	Fine aggregate	Angular particles	Improved interlocking	Higher water demand
Quarry dust	Fine filler	Void filling	Cost-effective	Fines control needed

Hollow bricks are characterized by a complex interrelation of binder chemistry, aggregate properties, and supplementary materials, which determine the mechanical strength of hollow bricks. In contrast to a solid masonry unit, hollow bricks have non-uniform distribution of stress because they have avoided geometry, and strength development in hollow bricks is especially sensitive to the material composition and microstructural integrity (40). As a result, the material constituents need to be optimized, so that the compressive, tensile, and flexural performance is sufficient.

Binder type also dominates in strength development control of the hollow bricks. The systems based on ordinary Portland cement (OPC) often have high compressive strength at early age because of the quick hydration and the development of calcium silicate hydrate (C-S-H) gels. The heat of hydration and shrinkage is however high with OPC that may cause microcracking particularly in thin webs and shells of hollow bricks resulting in variability in strength and long-term performance (41).

Hydration kinetics are altered and continuity of the matrix is enhanced with the addition of supplementary cementitious materials to blended binder systems. A low content of calcium hydroxide and fineness pore structure are also some of the characteristics that lead to an increase in long-term strength and decrease in brittle nature and this quality is more important to hollow masonry units with stress concentration (42).

Fly ash is one of the best-researched additional cementitious materials when used in hollow bricks production because of its pozzolanic activity as well as a spherical morphology of the particles. Many studies state the effect of partial substitution of cement with fly ash (usually 20-40) leads to slight decreases in the early-age strength but later substantial increases in the compressive strength at later ages (43–45). It is explained by the fact that the interaction between fly ash and calcium hydroxide is retarded, which results in the secondary formation of C-S-H and refinement of pores.

Fly ash in hollow bricks helps to achieve better packing of the particles and decreased micro-porosity which helps to increase the load to be transferred via the brick webs and shells (46). The reason is that the enhanced microstructural densification closes in on the existence of voids and results in more homogeneous stress distribution under compressive loading.

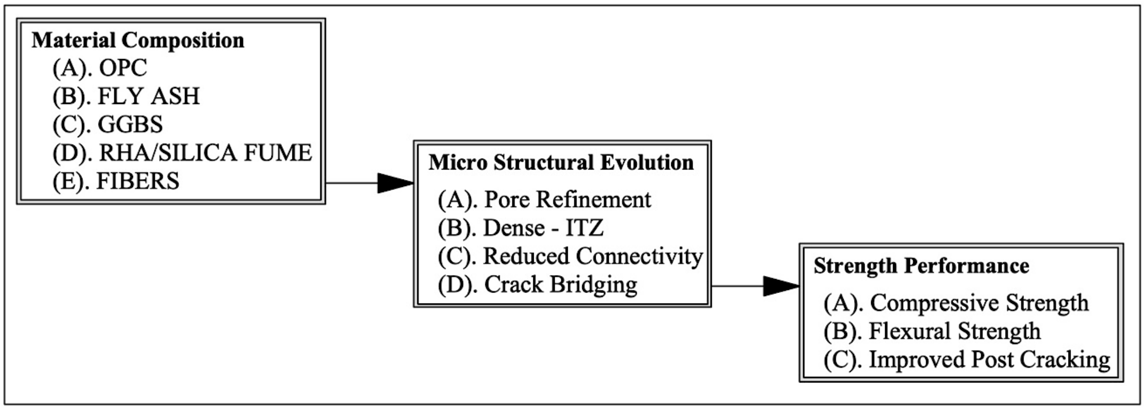

Figure 3: Relationship Between Material Composition, Microstructural Evolution and Strength Development in Hollow Bricks

Figure 3 illustrates the relationship between material composition, microstructural evolution, and strength development in hollow brick systems. The incorporation of supplementary materials and fibers contributes to pore refinement, improved ITZ densification, and enhanced crack-bridging mechanisms within the matrix. These microstructural modifications collectively improve compressive and flexural strength characteristics while also enhancing post-cracking performance. The figure highlights the mechanistic pathway governing strength enhancement in sustainable hollow brick composites.

Ground granulated blast furnace slag (GGBS) has latent hydraulic properties and has shown better performance when used in hollow brick applications as opposed to the conventional OPC systems. Upon activation in alkaline conditions, GGBS creates low-calcium C-S-H gels which are dense and increase the compressive strength and permeability (47, 48).

Research has shown that replacement percentage of GGBS of 30 percent to 50 percent can attain similar or better compressive strength than hollow bricks produced using OPC even at comparatively young age (49). The smaller heat of hydration of GGBS also limits thermal cracking and this is especially helpful to hollow bricks that have very thin load carrying sections.

Rice husk ash (RHA) and silica fume are high reactivity pozzolans that primarily affect strength in a micro-filler and nucleation effect. They have an ultra-fine size that enables them to occupy the capillary pores and enhance interfacial transition zone between the binder and aggregates (50, 51).

Such materials, even at low replacement levels (5-15%), are a great way to improve compressive and flexural strength by adding density to the matrix and a less dose distribution of flaws (52). This microstructural refinement becomes very essential in hollow bricks where stress concentrations are unavoidable to avoid premature cracking and loss of strength.

Aggregate grading and morphology have a very strong effect on strength development regulating the density of packing particles and the efficiency of transferring stress. High quality aggregate systems minimize the number of void contents in the matrix and ensure that there is equal redistribution of stress under compressive loads. Angular aggregates like manufactured sand and quarry dust can be used to increase mechanical interlocking which increases the compressive strength provided that the content of fines is regulated correctly (53, 54).

Optimized aggregate grading is of special concern in hollow bricks since concentration of stress due to localized interface between web-void may cause failure in case the surrounding matrix is weak or not packed (55).

Recent research points out the high performance of multi-component binder systems which incorporate fly ash, GGBS and high reactivity pozzolans. These ternary and quaternary systems weigh between early-age strength and long-term performance with the help of complementary hydration and pozzolanic mechanisms (56, 57).

These synergistic combinations have been found to enhance compressive, tensile, and flexural strength and decrease the variability with reference to curing conditions, and heterogeneity of materials. In the case of hollow bricks, such systems provide a good avenue to structural-grade performance using lesser cement content and higher sustainability.

The enhancement in strength and durability due to pore refinement and microstructural densification is primarily governed by hydration and pozzolanic reactions. During cement hydration, calcium silicate phases react with water to form calcium silicate hydrate (C–S–H), which is the primary binding phase responsible for strength development. Additionally, calcium hydroxide (CH) is generated as a by-product. Supplementary cementitious materials such as fly ash, GGBS, and silica fume react with this calcium hydroxide through pozzolanic reactions, leading to the formation of additional C–S–H. This secondary C–S–H contributes to pore refinement, reduces capillary porosity, and enhances matrix densification. In the case of GGBS, latent hydraulic reactions further contribute to the formation of a dense and durable microstructure. These mechanisms collectively improve strength, reduce permeability, and enhance long-term durability performance.

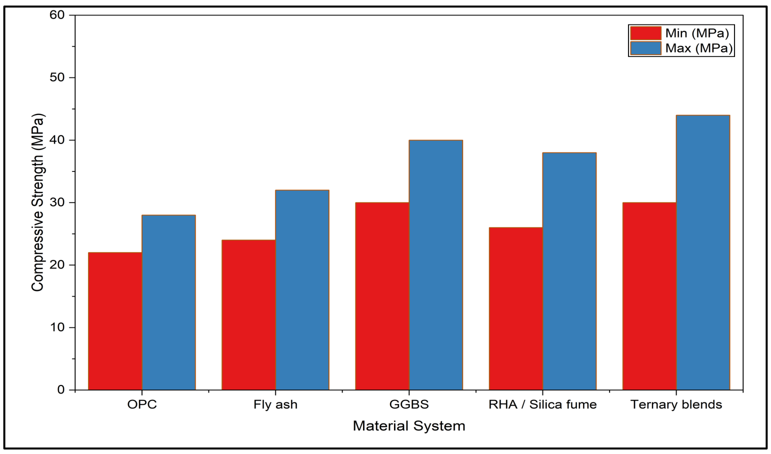

Figure 4: Reported Compressive Strength Ranges of Hollow Bricks with Different Material Systems

Figure 4 presents the reported compressive strength ranges of hollow bricks produced using different material systems. The incorporation of GGBS, RHA/silica fume, and ternary blends demonstrated notable improvements in compressive strength compared to conventional OPC-based systems. Ternary blended systems exhibited the highest maximum strength due to enhanced pozzolanic activity and improved matrix densification. The results indicate that optimized multi-component binder systems can significantly enhance the mechanical performance of hollow bricks.

Table 3: Influence of Supplementary Cementitious Materials on Strength Performance of Hollow Bricks

SCM type	Typical replacement level (%)	Effect on compressive strength	Effect on flexural/tensile strength	Key observations
Fly ash	20–40	↑ Long-term strength	Slight ↑	Improved pore refinement
GGBS	30–50	↑ Early and long-term strength	↑	Dense C–S–H formation
Rice husk ash	5–15	↑ Strength	↑ Flexural strength	Micro-filler effect
Silica fume	5–10	Significant ↑	Significant ↑	ITZ densification
Ternary blends	30–60 (combined)	Highest ↑	Highest ↑	Synergistic hydration

Table 3 summarizes the influence of different supplementary cementitious materials (SCMs) on the mechanical performance of hollow bricks. Materials such as fly ash, GGBS, rice husk ash, and silica fume contributed to improvements in compressive and flexural strength through pore refinement and enhanced hydration reactions. Among the investigated systems, ternary blends exhibited the highest overall strength enhancement due to synergistic microstructural development. The findings demonstrate the effectiveness of SCM incorporation in producing stronger and more durable hollow brick composites.

Incorporation of discrete fibers into hollow brick matrices has turned out as a viable approach to addressing the brittle nature of cementitious materials, as well as to contribute to tensile and flexural behaviour. Hollow bricks are especially vulnerable to the development and further spread of cracks under service and ultimate loading conditions because of the existence of vacuum areas and comparatively thin load-bringing areas (58). The fiber reinforcement enhances the crack resistance by sealing micro and macrocracks, reallocating the stresses, and increasing the post-cracking behavior, which increases the structural uses of hollow bricks.

The steel fibers are the best reinforcements to enhance the mechanical performance because of their high tensile strength, elastic modulus and crack-bridging ability. Steel fibers incorporated in hollow brick systems have been demonstrated to have a considerable positive impact on flexural strength, energy absorption and toughness (59, 60). The main strengthening mechanism is the fiber pull-out resistance which delays the crack opening and gives remaining load-carrying capacity after the cracking of the matrix.

Experiments have shown that at dosages of 0.5-1.5 percent by volume, steel fiber may significantly enhance flexural and splitting tensile strength as well as other properties without negatively impacting compressive strength in case it is well dispersed (61). Nonetheless, high fiber content can cause workability problems and fiber balling that could cause local defects and decrease performance consistency (62).

The benefits of glass fiber include low density, great tensile strength, and dispersion; thus, it is appealing to the lightweight masonry. Alkali-resistant (AR) glass fibers are also having a success in enhancing tensile and flexural strength of cementitious composites, such as hollow bricks (63). The strengthening process is correlated to crack bridging and midway the crack transfer of stress.

Although these advantages exist, the problem of fiber degradation in alkaline conditions is a very important factor of durability that needs attention. When appropriate alkali resistance is not supplied, long-term exposure to high-pH solutions in the pores may decrease the strength of the glass fibers (64). Therefore, the glass fiber-reinforced hollow bricks need a thorough selection of the material and compatibility evaluation to maintain a stable performance.

Synthetic fibers which are commonly used to contain plastic and dry shrinkage cracking include polypropylene (PP) and other synthetic fibers instead of necessarily increasing load-bearing capacity. The PP fibers are found to be effective in solidifying the premature microcracking of hollow bricks through limiting tensile stresses caused by shrinkage in the matrix (65).

Even though the PP fibers have low elastic modulus and tensile strength than steel fibers, their homogenous distribution and chemical inertness make them less prone to the crack propagation and have enhanced durability (66). It has been found that there are small increases in flexural strength and impact resistance, whereas compressive strength usually is not affected (67). The main advantage of PP fibers in hollow bricks consists in the improvement of serviceability and durability as opposed to structural strength.

Making fibers in hollow brick matrices transforms failure modes to become ductile behavior rather than brittle fracture, which is beneficial to the masonry system under dynamic load or accidental loads (68). Hollow bricks with fiber-modified have enhanced crack tolerance, lesser crack width, and increased post-peak load resistance, which has also led to better structural reliability.

Design wise, fiber reinforcement allows hollow bricks to perform to the needs of reinforcement masonry units, which may subsequently eliminate the need of further reinforcement in non-loading and lightly loaded structures (69). But there are still no standard design requirements about the fiber-reinforced hollow bricks, which emphasizes the necessity of additional studies and the creation of codes (70).

Table 4 presents the durability-related performance characteristics of hollow bricks produced using different material systems and fiber modifications. The incorporation of fly ash, GGBS, and RHA/silica fume significantly reduced water absorption and improved resistance against efflorescence and chemical attack. GGBS- and RHA/SF-based systems exhibited superior overall durability due to enhanced matrix densification and reduced pore connectivity. Fiber incorporation additionally contributed to crack control and long-term durability enhancement in hollow brick composites.

Table 4: Performance Characteristics of Fiber-Reinforced Hollow Bricks

Material System	Water Absorption	Efflorescence Resistance	Chemical Resistance	Overall Durability
OPC-based	High	Moderate	Moderate	Moderate
Fly ash–based	Reduced	Improved	Improved	Good
GGBS-based	Low	High	High	Very good
RHA / SF-based	Low	High	Moderate–high	Very good
Fiber-modified	Reduced cracking	Indirect improvement	Improved	Enhanced

A controlling parameter of the long-term performance and service life of hollow brick masonry is durability, especially when it is applied in harsh environmental conditions. Hollow bricks are prone to moisture infiltration, exposure to chemicals, and environmental cycling compared to solid masonry units due to the existence of internal cavities and thin load-carrying areas (71). Therefore, the material composition is a decisive factor in the regulation of the degradation rates and a durable performance.

Hollow bricks have one of the most vital durability indicators in the form of water absorption because the penetration of water has a direct impact on strength loss, efflorescence, and vulnerability to chemical action. The distribution of the size of pores in the binder matrix, pore connection, and surface tension influences the process of capillary absorption (72). Strong values of water absorption are normally accompanied by high degree of micro-porosity and poor interfacial transition zones.

Investigations have also demonstrated that the addition of supplementary cementitious constituents (fly ash, GGBS and silica fume) can avert the uptake of water and sorptivity as they refine pore structure and interfere with the continuity of capillaries (73, 74). Hollow bricks are especially susceptible to associated with diminished water transport since the presence of moisture in regions adjacent to voids may enhance the local deterioration and diminish the load-bearing capacities.

Efflorescence is a normal problem in masonry durability and aesthetics, which occurs due to the movement of soluble salts to the surface in the presence of moisture. Moorish geometry Void geometry has been found to be particularly susceptible to efflorescence because of higher moisture pathways and surfaces of evaporation (75).

The composition of the materials has a great impact on the susceptibility of efflorescence. The content of high calcium hydroxide and excessive supply of alkali make the soluble salts more accessible, and the utilization of pozzolanic materials decreases the free lime by the secondary hydration reactions. The modified systems containing fly ash and GGBS have been shown to exhibit enhanced resistance to efflorescence because of reduced pore connectivity, as well as reduced alkali mobility (76).

In industrial or coastal locations, hollow bricks can be subjected to the influence of harmful chemical factors, such as sulfates, chlorides, and acidic conditions. Sulfate attack gives rise to expansive products of reaction like ettringite and gypsum, which result in cracking and strength loss (77). In acid attack, the calcium-based hydration products are dissolved progressively on the other hand.

Hollow bricks made in terms of SCM have more resistance to the chemical attack because of the decreased level of calcium hydroxide and the creation of more compact hydration products (78). Specifically, GGBS-modified systems demonstrate a high level of sulfate resistance and decreased chloride penetration and can be used in aggressive exposure environments.

To provide a consistent comparison of the effects of different supplementary cementitious materials, quantitative trends reported in literature are summarized. Fly ash replacement levels of approximately 20–40% are generally associated with long-term compressive strength improvements in the range of 10–25%, primarily due to secondary C–S–H formation and pore refinement. Ground granulated blast furnace slag (GGBS), when used at replacement levels of 30–50%, has been reported to enhance compressive strength by approximately 15–30% and significantly improve durability through reduced permeability and chloride ingress. Silica fume, typically used at lower replacement levels of 5–10%, can result in compressive strength increases of up to 20–25% due to its micro-filler effect and improved interfacial transition zone (ITZ) densification. These quantitative comparisons provide a consistent basis for evaluating the performance of different SCMs in hollow brick systems.

The quantitative comparison of SCM effects is summarized in Table 5.

Table 5 presents a quantitative comparison of various supplementary cementitious materials (SCMs) used for enhancing the strength and durability performance of hollow bricks. Materials such as fly ash, GGBS, silica fume, and rice husk ash demonstrated notable improvements in compressive strength and permeability resistance through pozzolanic and micro-filler mechanisms. Among the investigated systems, ternary blends exhibited the highest combined performance due to synergistic hydration and pore refinement effects. The results highlight the effectiveness of SCM-based modification in developing durable and high-performance hollow brick systems.

Table 5: Quantitative Comparison of Supplementary Cementitious Materials on Strength and Durability Performance

SCM Type	**Typical Replacement (%)**	**Compressive Strength Improvement**	**Durability Improvement**	**Key Mechanism**	**References**
Fly Ash	20–40%	↑ 10–25% (long-term)	↓ Permeability (20–35%), ↓ water absorption	Pozzolanic reaction, secondary C–S–H	(68, 75)
GGBS	30–50%	↑ 15–30%	↓ Chloride ingress, ↓ permeability	Latent hydraulic reaction, dense C–S–H	(35)
Silica Fume	5–10%	↑ 20–25%	↓ Porosity, ↑ durability	Micro-filler effect, ITZ densification	(18)
Rice Husk Ash	5–15%	↑ 10–20%	↓ Water absorption, ↑ durability	High pozzolanic reactivity	(22)

Ternary Blends	30–60% (combined)	↑ 20–35%	Significant durability enhancement	Synergistic hydration + pore refinement	(35)

Due to the presence of wet-dry cycles, variation of temperatures and exposure to ultraviolet radiations, weather processes can also greatly influence the long-term durability of hollow bricks. The cyclic movement of moisture Favors microcrack growth and progressive mechanical integrity deterioration particularly to porous matrices.

Material systems that exhibit a refined pore structure and have a higher continuity of the matrix are characterized by better resistance to degradation that occurs with weathering. It has been demonstrated that the development of cracks and the strength retention under long-term environmental conditions can be reduced using blended binders and optimized curing regimes.

Conditions during which a hollow brick is cured are very critical in determining the durability performance of the hollow bricks in terms of hydration completeness and microstructural development. Poor curing causes poor hydration, high porosity and low moisture and chemical ingress resistance. The quality of curing is especially sensitive in the case of systems containing SCM because long periods of moisture presence are necessary to promote pozzolanic and latent hydraulic reactions.

Also optimized regime of curing has been proved very beneficial in augmenting durability through densifying the matrix and facilitating interfacial bonding, thus, lowering the risks of degradation in the long run in the hollow brick masonry (79).

Table 6 summarizes the influence of different fiber types on the strength and durability performance of hollow bricks. Steel fibers exhibited significant improvements in flexural and tensile behavior through effective crack-bridging action, whereas glass fibers enhanced stress redistribution within the matrix. Polypropylene fibers primarily contributed to shrinkage control and reduction of microcracking, thereby improving serviceability characteristics. The results indicate that fiber incorporation can substantially enhance the structural reliability and long-term durability of hollow brick composites.

Table 6: Effect of Material Composition on Durability Performance of Hollow Bricks

Fiber Type	Typical Dosage	Primary Mechanism	Strength Improvement	Durability Implication	Structural Relevance
Steel fibers	0.5–1.5%	Crack bridging	↑ Flexural and tensile	Improved crack control	Semi-structural use
Glass fibers (AR)	0.5–1.0%	Stress redistribution	↑ Flexural	Alkali sensitivity	Non-load bearing
Polypropylene	0.1–0.5%	Shrinkage control	Minor	Reduced microcracking	Serviceability

Along with mechanical power and durability, sustainability performance of hollow bricks has also been an essential factor in the modern construction as the regulatory and environmental pressure continues to rise. The material efficiency of hollow geometry, coupled with an efficient material composition, opens the opportunities of minimizing the operational as well as embodied environmental effects.

Internal voids present in hollow bricks decrease thermal conductivity of hollow bricks in comparison with solid masonry units and hence enhance building energy efficiency. The main factors that control thermal performance are the void geometry, porosity and the density of the material that determine the pathways of heat transfer (80). Incorporation of lightweight aggregates and additional cementitious substances also improves the thermal insulation through the enhancement of air entrainment and lowering the solid-phase conductivity. Better thermal performance has a direct effect of lowering operational energy requirement during the service life of the building, especially in hot and temperate climate.

Life Cycle Assessment (LCA) of Hollow Brick Materials

Life cycle assessment has turned out to be a very strong instrument of construction materials quantification of the environmental effects of construction materials in various life cycle versions. When considering hollow bricks, most reported studies use either cradle-to-gate or cradle-to-grave system boundaries, looking at the extraction of raw materials, its manufacture, transportation, and use, and the end-of-life stages (81).

The evidence of LCA always shows that when partial substitution of cement with industrial by-products like fly ash and GGBS is considered, the embodied energy and carbon emission reduces significantly. The reduction of cement clinker is the most significant variable that regulates the impact on the environment and usually overpowers the consequences of transportation and manufacturing energy. Optimized hollow brick compositions offer a good balance between structural performance and environmental sustainability when they are combined with improvement of durability and service life.

Quantitative life cycle assessment (LCA) studies have consistently demonstrated that the incorporation of supplementary cementitious materials (SCMs) such as fly ash and ground granulated blast furnace slag (GGBS) leads to significant reductions in environmental impacts associated with cement-based materials. The primary contributor to embodied carbon in masonry products is the clinker production process, which is highly energy-intensive and responsible for substantial CO_2 emissions. Partial replacement of Portland cement with SCMs reduces clinker demand, thereby directly lowering greenhouse gas emissions and energy consumption.

Reported LCA studies indicate that CO_2 emission reductions in the range of approximately 20% to 45% can be achieved depending on the level of cement substitution and system boundaries considered. Similarly, embodied energy reductions of about 15% to 35% have been documented due to the lower energy requirements associated with SCM processing compared to clinker production. In addition to embodied impacts, improved durability resulting from pore refinement and enhanced microstructural densification contributes to extended service life, thereby reducing maintenance frequency and life cycle environmental burdens.

Furthermore, the improved thermal performance of hollow brick systems, attributed to their void structure and reduced density, contributes to lower operational energy consumption in buildings, particularly in hot and temperate climates. These combined effects demonstrate that optimized hollow brick compositions not only enhance mechanical and durability performance but also provide substantial environmental benefits across both embodied and operational phases of the life cycle.

Overall, the integration of SCMs and optimized material design in hollow bricks aligns with sustainable construction practices by reducing resource consumption, minimizing carbon emissions, and improving long-term performance, thereby supporting global sustainability objectives.

Contribution to Sustainable Development Goals (SDGs)

The use of sustainable hollow bricks materials is in line with various United Nations Sustainable Development Goals. SDG 12 (Responsible Consumption and Production) is supported using industrial by-products and efficient use of materials (SDG 12) that ensure the efficiency of resources and valorization of waste. The enhancement of durability and structural reliability can be linked to SDG 9 (Industry, Innovation, and Infrastructure) as it will allow having resilient and sustainable construction systems. Improved thermal and lower embodied carbon directly promotes SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action) by lowering energy consumption and greenhouse gases (82).

With the incorporation of material optimization, durability improvement, and the LCA-based evaluation, hollow brick systems may contribute to a great number of sustainability goals in the built environment (83).

Table 7 summarizes the life cycle assessment (LCA) findings reported for various sustainable hollow brick systems. The incorporation of supplementary cementitious materials such as fly ash and GGBS significantly reduced CO_2 emissions and overall environmental impact compared to conventional OPC-based bricks. GGBS- and optimized blended systems demonstrated superior sustainability performance due to extended service life and reduced energy demand. The findings highlight the environmental advantages of adopting SCM-based hollow brick technologies in sustainable construction practices.

Table 7: Summary of Life Cycle Assessment (LCA) Findings for Sustainable Hollow Brick Systems

Material System	LCA Boundary	Main Indicator	Environmental Outcome	Key Implication
OPC hollow brick	Cradle-to-gate	CO_2 emissions	High	Cement dominant
Fly ash brick	Cradle-to-gate	CO_2 reduction	↓ 20–35%	SCM substitution benefit
GGBS brick	Cradle-to-grave	Energy and CO_2	↓ 30–45%	Long service life
Optimized hollow brick	Cradle-to-grave	Total impact	Lowest	Combined benefits

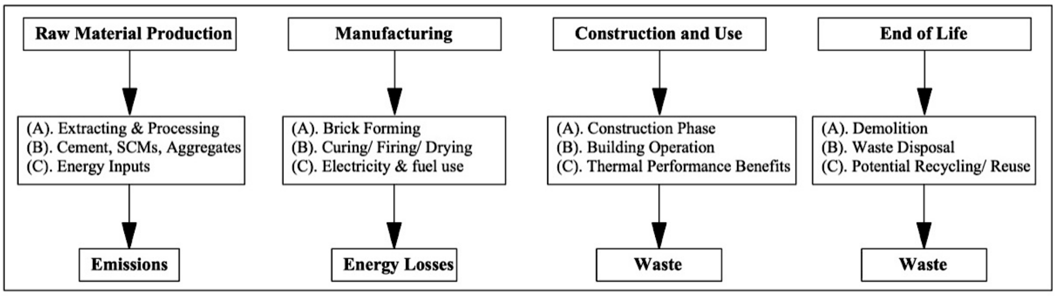

Figure 5: Life Cycle Assessment (LCA) System Boundary for Hollow Brick Materials

Figure 5 illustrates the system boundary considered in the life cycle assessment (LCA) of hollow brick materials, covering stages from raw material extraction to end-of-life management. The framework includes material processing, manufacturing operations, construction usage, and demolition-related impacts. Emissions, energy losses, and waste generation were identified as the major environmental contributors across the life cycle stages. The figure highlights the importance of integrated sustainability assessment for evaluating eco-efficient hollow brick systems.

Microstructural characterization techniques play a crucial role in understanding the relationship between material composition and performance of hollow bricks. Scanning Electron Microscopy (SEM) is widely used to examine the morphology of the matrix, pore structure, and interfacial transition zone (ITZ), enabling visualization of microcracks and hydration products at high resolution. X-ray Diffraction (XRD) is employed to identify crystalline phases such as calcium hydroxide, ettringite, and other hydration products, providing insight into reaction mechanisms and phase development. Mercury Intrusion Porosimetry (MIP) is commonly used to quantify pore size distribution, total porosity, and pore connectivity, which are directly related to permeability and durability performance. The combined application of these techniques enables a comprehensive evaluation of microstructural evolution and its influence on mechanical strength, permeability, and long-term durability of hollow brick systems (84).

Discussion

The results summarized in the previous sections prove that the functioning of hollow bricks cannot be sufficiently measured, through the isolated analysis of strength, durability, or sustainability factors. Rather, the coupled effect between the material composition, microstructural development, mechanical response, durability resistance, and environmental impact determines hollow brick behavior. To be able to replace existing knowledge and set future material optimization, a unified framework is suggested that interrelates these governing parameters in a systematic way.

The chemical and physical mechanisms that lead to the development of microstructures in hollow bricks are determined by material composition. Hydration, pozzolanic and latent hydraulic reactions are controlled by binder chemistry and are in turn determined by the pore size distribution, pore connectivity, and quality of interfacial transition zone (ITZ). The addition of auxiliary cementitious materials facilitates pore refinement and a buildup of the matrix whereas optimized grading of aggregates advances the packing of particles and lessens heterogeneity of the microstructure. Fiber reinforcement also increases microstructure by halting the formation of cracks and reducing the growth of cracks, increasing the continuity of the matrix both in the face of mechanical and environmental loading (85).

The quality of the interfacial transition zone (ITZ) plays a critical role in governing durability performance, particularly in terms of permeability and chloride diffusion. A dense and well-bonded ITZ reduces the presence of microcracks and limits the formation of preferential pathways for fluid transport, thereby significantly lowering permeability, and water ingress. Conversely, a porous and weak ITZ acts as a primary conduit for moisture and aggressive ions, accelerating chloride penetration and increasing the risk of durability-related degradation. The incorporation of supplementary cementitious materials such as silica fume and fly ash (86) has been shown to refine the ITZ by reducing calcium hydroxide content and promoting secondary C–S–H formation, resulting in reduced pore connectivity and improved resistance to chloride diffusion. Therefore, the enhancement of ITZ quality is directly associated with improved durability metrics, including reduced permeability and lower chloride ingress in hollow brick systems.

Microstructural properties provide the point of critical contact between the material composition and its performance. A fine and irregular pore structure enhances compressive, tensile, and flexural strength by allowing greater transfer of stress by the load bearing webs and shells of hollow bricks. At the same time, lower pore connectivity decreases moisture entry and ion movement, which increases water absorption resistance, efflorescence, chemical, and weathering resistance. This framework emphasizes the fact that the process of strength enhancement and durability improvement cannot be thought of as independent goals but must be seen as complementary consequences achieved by the process of microstructural optimization (87, 88).

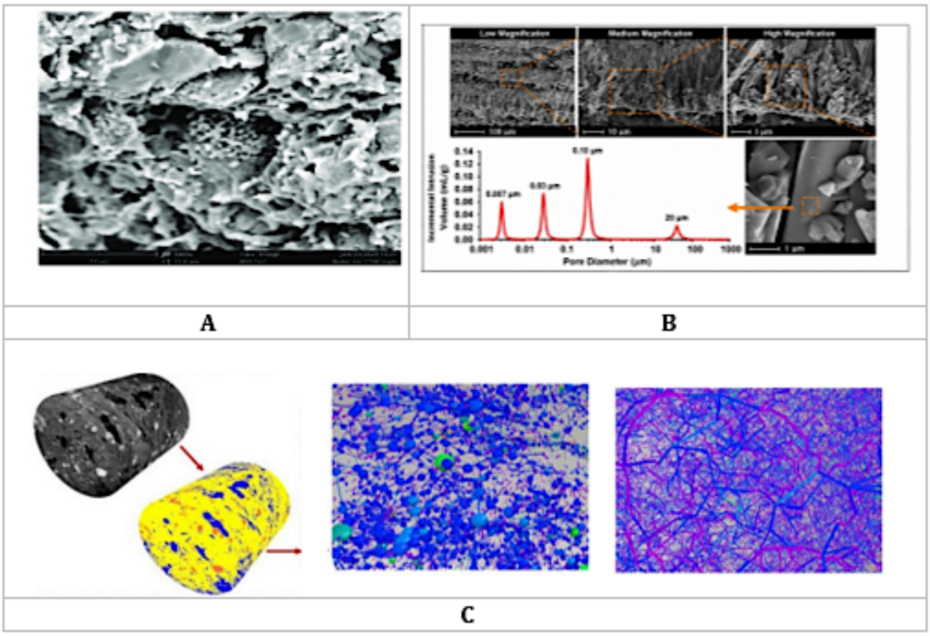

Figure 6: Microstructural Characterization Techniques Used for Masonry Materials. (A) SEM Image Showing Pore Morphology and Mineral Phases in Brick Microstructure (89), (B) Mercury Intrusion Porosimetry (MIP) Pore Size Distribution Curve (90), (C) Micro-CT Visualization of the Three-Dimensional Pore Network in Brick Materials (91)

Figure 6 presents various microstructural characterization techniques employed for evaluating masonry and hollow brick materials. SEM analysis was used to examine pore morphology, hydration products, and interfacial microstructural features within the brick matrix. Mercury intrusion porosimetry (MIP) enabled assessment of pore size distribution and connectivity characteristics, while micro-CT imaging provided three-dimensional visualization of internal pore networks. These techniques collectively assist in understanding the relationship between microstructure and engineering performance of hollow brick systems.

Hollow brick masonry systems have a service life, which is dependent on mechanical strength and durability. Long service life means that the maintenance needs and the frequency of replacement will decrease and this will in turn decrease the environmental impacts of the life cycle. Optimized hollow brick compositions made of reduced cement content and the use of industrial by-products when combined have a positive environmental impact in both embodied and operational impact categories. This interconnection highlights the need to ensure hollow bricks are designed with strong performance relating to compliance with strength at first instance, but also in terms of durability and sustainability (92).

Although a full statistical meta-analysis is beyond the scope of the present study, a quantitative synthesis of key findings has been incorporated based on reported literature. Previous studies indicate that fly ash replacement (20–40%) can enhance long-term compressive strength and reduce permeability due to secondary C–S–H formation (93). Similarly, GGBS incorporation (30–50%) has been associated with improved strength development and enhanced durability performance, particularly in terms of reduced chloride ingress and permeability. The addition of silica fume (5–10%) significantly improves compressive strength and interfacial transition zone (ITZ) densification due to its micro-filler effect and high pozzolanic reactivity. These quantitative trends support the thematic classification and strengthen the interpretation of material-performance relationships (94, 95).

Due to the evidence synthesized, a sustainability-focused decision model is offered to hollow brick material design. The framework prioritizes:

(a) properties of the binder systems are undergoing changes towards low-clinker or blended systems,
(b) maximization of aggregate grading and geometry of void,
(c) focused on using fibers to control crack and serviceability improvement, and
(d) environmental performance by means of life cycle assessment.

With this combined strategy, designers and researchers can promote structural needs, durability resistance, and environmental targets to support the creation of the next-generation hollow brick systems that are consistent with the current sustainability requirements.

The proposed framework can be further substantiated through quantitative relationships reported in literature. A reduction in total porosity and refinement of pore size distribution is consistently associated with increased compressive strength and reduced permeability, as a denser microstructure enhances load transfer and limits fluid ingress (96, 97). Similarly, increasing the replacement level of supplementary cementitious materials (SCMs) such as fly ash and GGBS is correlated with significant reductions in permeability and chloride diffusion due to the formation of additional C–S–H and improved pore structure (98, 99). These correlations highlight that material composition directly governs microstructural characteristics, which in turn control both mechanical strength and durability performance. Incorporating such quantitative relationships strengthens the validity of the proposed integrated framework as reported in previous studies.

Table 8 presents the relationship between various material design strategies, microstructural modifications, and their corresponding performance and sustainability outcomes in hollow brick systems. SCM substitution and optimized grading contributed to pore refinement and dense particle packing, resulting in improved strength and reduced permeability. Fiber reinforcement enhanced crack resistance and service life, while hollow geometry reduced structural weight and operational energy demand. The table highlights the integrated role of material design in achieving both engineering efficiency and sustainability objectives.

Table 8: Mapping of Material Design Strategies to Performance Outcomes and Sustainability Objectives

Design Strategy	Microstructural Effect	Strength Benefit	Durability Benefit	Sustainability Outcome
SCM substitution	Pore refinement	↑ Long-term	↓ Permeability	↓ Embodied carbon
Optimized grading	Dense packing	↑ Compressive	↓ Water ingress	Material efficiency
Fiber reinforcement	Crack control	↑ Flexural	↑ Service life	Reduced maintenance
Hollow geometry	Reduced density	Adequate strength	Improved thermal	↓ Operational energy

Conclusion

This state-of-the-art review comprehensively examined the influence of material composition on the strength, durability, and sustainability performance of hollow bricks by synthesizing findings from high-quality experimental and analytical studies. The review demonstrated that the performance of hollow bricks is governed by the interdependent relationship among binder chemistry, aggregate characteristics, supplementary cementitious materials, fiber reinforcement, and the resulting microstructural development. Conventional Portland cement-based hollow bricks were found to provide adequate mechanical strength; however, limitations associated with long-term durability and environmental impact remain significant concerns. The incorporation of supplementary cementitious materials such as fly ash, ground granulated blast furnace slag, rice husk ash, and silica fume substantially improved long-term mechanical performance and durability through pore refinement, densification of the interfacial transition zone, and reduction in permeability.

These improvements are particularly important in hollow bricks, where void-induced stress concentrations demand enhanced matrix integrity. In addition, steel and polypropylene fiber reinforcement effectively enhanced crack resistance, post-cracking behaviour, and serviceability, thereby improving the structural reliability of hollow brick masonry systems. Durability-related performance was identified as a major factor influencing the service life of hollow bricks, as optimized material compositions exhibited lower water absorption, improved resistance to efflorescence, superior chemical stability, and enhanced weathering resistance, particularly under appropriate curing conditions. From a sustainability perspective, life-cycle-based assessments indicated that hollow brick systems incorporating industrial by-products significantly reduced embodied energy and carbon emissions, while improved thermal insulation performance contributed to lower operational energy demand.

The integrated assessment framework proposed in this review highlighted that strength, durability, and sustainability should not be considered as isolated parameters but rather as interconnected performance criteria for the development of high-performance hollow brick systems. Nevertheless, this study is limited by the dependence on previously published experimental investigations with varying material compositions, testing methodologies, curing conditions, and regional standards, which may affect direct comparison of results and universal generalization of findings. Furthermore, limited long-term field performance data and the absence of standardized sustainability assessment frameworks restrict the ability to establish definitive design recommend-dations. Therefore, future research should focus on long-term in-service performance monitoring, durability-based service life prediction models, advanced microstructural characterization, and standardized testing methodologies for sustainable hollow brick systems.

Additional studies integrating life-cycle assessment, structural reliability, thermal efficiency, and economic feasibility are also necessary to support the large-scale implement-tation and codification of optimized hollow brick materials in modern construction practices.

Abbreviations

GGBFS: Ground Granulated Blast Furnace Slag, LCA: Life Cycle Assessment, PP: Polypropylene, SCMs: Supplementary Cementitious Materials, SDGs: Sustainable Development Goals, SEM: Scanning Electron Microscopy.

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Author Contributions

Maddikera Lokanath Reddy: Conceptualization, literature review, methodology design, data synthesis, analysis, manuscript writing, review & editing, Lingeshwaran N: Literature review support, data compilation, critical review, manuscript editing.

Conflict of Interest

The author declares that there are no known financial or personal conflicts of interest that could have influenced the work reported in this paper.

Data Availability

No new experimental data were generated or analyzed in this study. All data discussed are derived from previously published peer-reviewed literature, which are cited within the manuscript.

Declaration of Artificial Intelligence (AI) Assistance

During the preparation of this manuscript, generative AI tools were used to assist with language refinement, grammar correction, and formatting improvements. The author reviewed and edited all content to ensure accuracy, originality, and compliance with academic standards. The author takes full responsibility for the final content of the manuscript.

Ethics Approval

This study is a review-based research article and does not involve human participants, animal experiments, or sensitive personal data. Therefore, ethical approval was not required.

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