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A Mini-Review on the Use of Recycled Plastic and Crushed Glass in the Production of Sustainable Bricks

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With growing concern over environmental degradation and the depletion of natural resources, the integration of waste-derived materials into construction has gained significant attention. Among the most problematic yet reusable waste types are recycled plastic and crushed glass, both of which pose long-term environmental challenges if left unmanaged. This mini-review explores their potential application in the development of sustainable bricks, using sand as a base aggregate. Recycled plastic improves thermal insulation and reduces water absorption due to its hydrophobic nature, while crushed glass contributes to enhanced compressive strength and structural integrity. When used in optimized proportions, such as 10% plastic or 20% crushed glass, these materials have been shown to produce bricks that meet or exceed conventional performance benchmarks. This review synthesizes findings from recent experimental studies, focusing on mechanical properties, thermal resistance, and environmental benefits. The incorporation of these materials also supports circular economy goals by reducing landfill waste and decreasing reliance on virgin sand and clay resources. The findings demonstrate a promising pathway toward more sustainable, durable, and efficient construction materials. Current research gaps and future directions are also discussed to guide further innovation in eco-friendly brick production.

Keywords: Crushed glass, mechanical properties, recycled plastic, sustainable bricks, waste utilization

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The construction sector significantly contributes to global carbon emissions due to high energy demand and reliance on virgin raw materials. As sustainability becomes increasingly urgent, alternative materials like recycled plastic and crushed glass are gaining prominence in brick production. These materials, if unmanaged, pose environmental risks but also offer engineering benefits: plastic improves insulation and water resistance, while crushed glass enhances compressive strength and sintering behavior. Although extensively studied individually, their combined potential in a unified composite matrix remains underexplored. This review synthesizes recent findings on the use of sand-based bricks incorporating recycled plastic and crushed glass, focusing on mechanical, thermal, and environmental performance, while identifying research gaps for advancing durable, eco-friendly construction materials.

To illustrate the comparative performance and production potential of these alternative masonry materials, Figure 1 compares conventional fired clay bricks with sustainable bricks incorporating recycled plastic and crushed glass. The chart reports representative values of compressive strength, water absorption, and thermal conductivity selected from the experimental ranges summarised in this review, showing that appropriately designed sustainable bricks can achieve higher strength, lower moisture uptake, and improved thermal insulation relative to traditional units. The underlying datasets and variability of these properties are discussed in detail in the subsequent sections on mechanical behaviour, durability, and thermal performance.

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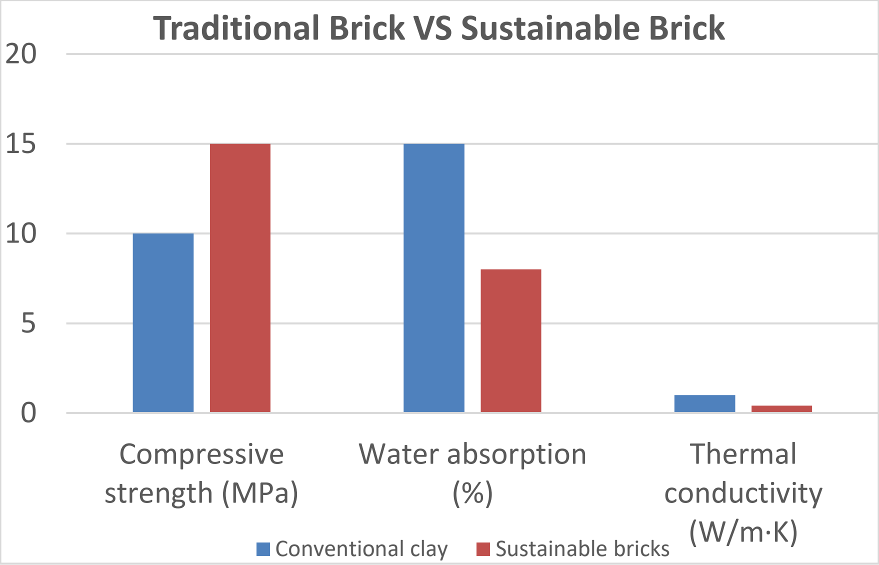

Figure 1. Comparison between traditional bricks and sustainable bricks.

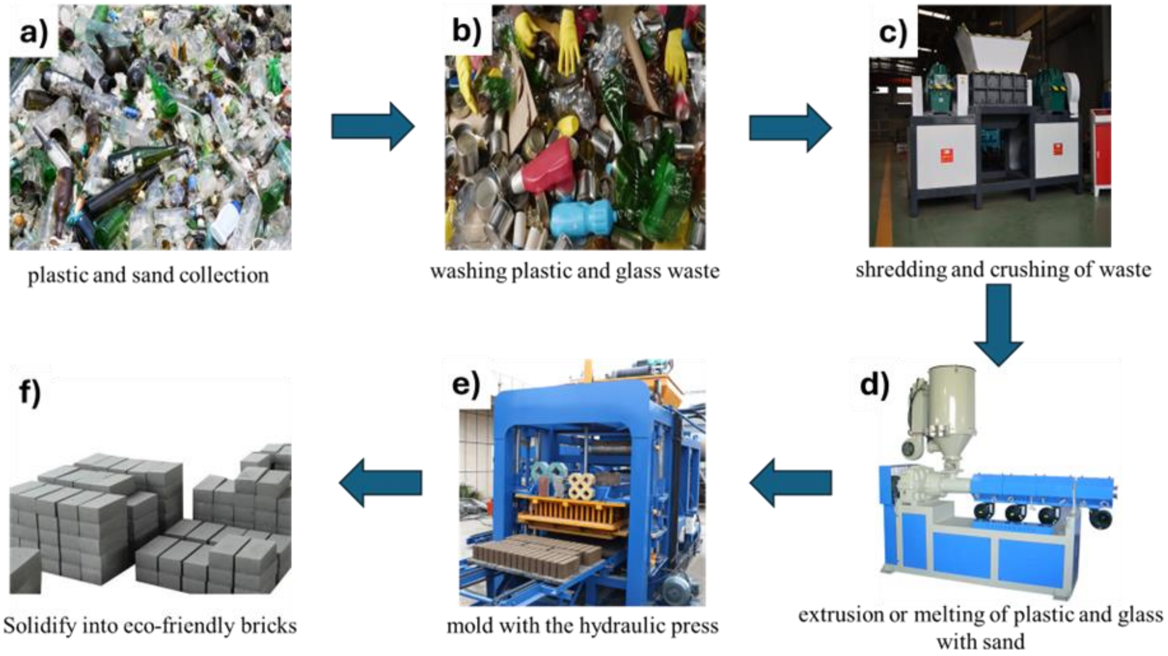

Figure 2. Visualization of the sustainable brick manufacturing process. (a) Collection of discarded glass waste [1], (b) Sorting of mixed waste materials including plastic and glass [2], (c) Shredding process for plastic and glass [3], (d) Extrusion process to form the composite mixture [4], (e) Hydraulic pressing for brick formation [5], (f) Final eco-friendly bricks ready for construction [5].

In addition, Figure 2 outlines the typical production process of sustainable bricks utilizing post-consumer plastic and glass waste. Beginning with waste collection and segregation, the process involves shredding and extrusion, followed by mold pressing and final curing into eco-friendly bricks. This schematic workflow demonstrates a low-energy, scalable method for converting waste into high-value construction materials while supporting circular economy principles.

Sand is vital in brick manufacturing, affecting workability, mechanical strength, and thermal insulation. Its silica content enhances structural integrity and limits shrinkage during firing [6]. Optimal particle grading reduces porosity, moisture-related degradation, and drying cracks, while improving load-bearing capacity and water resistance [7]. Sustainable substitutions like waste foundry sand or crushed glass can replace up to 20% of natural sand without compromising performance, supporting circular resource use [8].

Recycled plastic addresses pollution while enhancing structural and thermal properties in bricks. Common types include PET, PP, PS, HDPE, and LDPE, with PET favored for durability and non-toxicity [9].

Integration methods vary, including plastic-sand composites, plastic-soil bricks, and binder-based plastic bricks, each yielding compressive strengths between 12–35 MPa [10]. These bricks also exhibit low water absorption and thermal conductivity, improving durability and energy efficiency [11], [12]. Additionally, they reduce emissions and manufacturing costs [13, 14,15] Despite these benefits, several performance challenges remain, including inconsistent bonding, limited high-temperature resistance, the absence of dedicated standards, and public scepticism about the long-term reliability of plastic-rich masonry units. Fire behaviour is particularly critical, because thermoplastic phases soften, melt and can contribute to spalling and strength loss when exposed to elevated temperatures, as observed in concrete where recycled PET aggregates replaced up to 30% of coarse aggregate and were tested at about 700 °C [14, 15]. Recent work on plastic-containing bricks and blocks suggests several engineering strategies, including limiting plastic content, using sand–plastic composites or confined plastic cores, and applying protective layers or coatings, but systematic fire testing of plastic-infused bricks and wall assemblies is still scarce [16, 17].Further research is essential for optimizing performance and large-scale adoption.

Crushed glass, rich in silica, acts as a fluxing agent, lowering sintering temperatures and enhancing brick density and strength [18]. Replacing 15–30% of clay or sand with crushed glass has achieved compressive strengths up to 41 MPa [19]. It improves vitrification, shrinkage control, particle bonding, and thermal insulation [20]. Environmentally, it diverts glass waste from landfills and reduces energy consumption by 5–10% during firing. Overall, crushed glass supports mechanical, thermal, and environmental improvements in su Although many studies simply note alkali–silica reaction (ASR) as a potential risk in glass-containing systems, the severity of expansion strongly depends on glass content, particle fineness, and pore-solution chemistry, as shown for concretes and mortars with waste glass aggregates and powders [21, 22]. When waste glass is ground to a fine powder (typically <75 µm), it behaves predominantly as a supplementary cementitious material, consuming portlandite and refining the pore structure, which can significantly reduce ASR-induced damage [21, 22], [23]. Supplementary cementitious materials such as fly ash and glass powder themselves have been shown to mitigate ASR in glass-containing mixtures by lowering alkali concentration and modifying gel chemistry, although their effectiveness is sensitive to replacement level and glass gradation [21, 24]. Several recent studies that reported negligible ASR at relatively high glass contents either used substantial SCM dosages or did not fully document SCM proportions and glass particle-size distributions, making it difficult to define safe envelopes for glass-rich bricks and underlining the need for more mechanistic, long-term investigations in masonry systems [21, 22, 24]. stainable brick manufacturing.

MECHANICAL PERFORMANCE AND DURABILITY

This section reviews the mechanical performance of bricks incorporating recycled plastic and crushed glass as alternative materials. It focuses on compressive strength, load-bearing capacity, and structural stability based on findings from recent experimental studies.

Compressive Strength

Bricks with alternative sand sources demonstrate a wide range of compressive strengths depending on composition. For example, 50% waste foundry sand achieves 3.3 MPa [25], 20% M-Sand yields 2.81 MPa [7], and 15% quarry dust reaches 3.8–4.0 MPa [26]. meeting structural standards. Incorporating 10% hydrated lime significantly enhances the strength to 21.96 MPa [27]. Agro-industrial wastes such as bagasse ash and marble dust also maintain integrity [28], while low HDPE substitutions (2.5–3.5%) show potential, though specific MPa values are not fixed [29].

Recycled plastic in bricks offers sustainability advantages, but reduces strength due to weak bonding with cement [30, 31]. This loss of strength is closely linked to the characteristics of the plastic–cement interfacial transition zone (ITZ) rather than to the stiffness contrast alone. Microstructural and durability studies on concrete with recycled plastic aggregates report that the hydrophobic, chemically inert surface of polyethylene terephthalate (PET) and other plastics limits wetting and nucleation of hydration products, producing a more porous ITZ and facilitating debonding under thermal and mechanical loading [32, 33]. Cracks therefore, tend to initiate and propagate along plastic–paste interfaces, consistent with the observed reductions in compressive strength at higher plastic replacement levels and after thermal cycling [32, 33]. By contrast, studies that modify the plastic surface or confinement conditions such as the use of treated PET aggregates or purpose-designed plastic bricks, report denser interfaces and smaller strength penalties, highlighting the importance of ITZ engineering for plastic-rich masonry units [14], [16]. PET and PP at 10% replacement cause minimal losses, remaining suitable for non-load-bearing use [31]. Lower PET dosages (e.g., 0.5%) improve outcomes, while plastic fibers enhance flexibility and crack resistance in SCC [34, 35]. Surface-treated plastics perform better, showing only 5% strength loss compared to 15% for untreated [36]. Predictive machine learning tools further aid in optimizing mixes [37, 38]. Despite trade-offs, recycled plastic bricks are lightweight, water-resistant, and thermally efficient [39], though further research is needed to enhance bond quality.

Crushed glass (CG), used as a partial fine aggregate replacement, also shows strong potential when applied in optimal ratios. At 15% content, compressive strength reached 34.54 MPa, exceeding the 32 MPa benchmark for conventional concrete [40]. While [41] observed a 6% strength increase at 30% CG content, performance declined at higher levels due to poor particle packing and the risk of alkali-silica reaction (ASR). In masonry, bricks incorporating 20–40% crushed glass and PET achieved 54.85% higher strength than clay bricks and met SANS 227 load-bearing standards [42]. When these individual results are viewed together, a clear pattern emerges: mixes with about 15–20% crushed glass typically achieve peak compressive strengths, while higher glass dosages tend to reduce strength, consistent with observations that excessive glass can disrupt particle packing and increase ASR susceptibility [43]. Similarly, low recycled-plastic contents around 10% can still satisfy non-load-bearing strength requirements but generally reduce strength compared to controls, unless packing and ITZ conditions are improved by using finer, reactive mineral additions or well-graded sand, as highlighted in recent reviews on recycled plastic in cementitious composites [36]. Additionally, 10–15% CG used in soil stabilization significantly improved compressive and shear strength, with increases of up to 244% [44, 45]. At the material scale, compressive strength in sand-based bricks is strongly influenced by particle size, composition, moisture content, and binder type. Finer sand particles (<425 µm) enhance compaction and interlocking, increasing compressive strength (Patil). The use of industrial by-products such as granite dust and foundry sand further improves performance. For instance, replacing natural sand with granite dust increases toughness and reduces porosity [47], while a 70:30 sand-to-foundry-sand ratio enhances both compressive strength and dynamic modulus [48]. Pozzolanic additives like silica fume or nano-silica activate calcium-silicate-hydrate (C-S-H) formation, reinforcing structural integrity [49]. Stabilizing sand with ceramic waste or kiln dust also contributes to improved mechanical behavior [50]. These findings affirm that crushed glass can improve structural performance when used within safe limits, as shown in Table 1.

Table 1. Summary of compressive strength of sand and recycled plastic, and crushed glass.

Sand			
Reference	Material Composition	Compressive Strength (MPa)	Notes
[25]	50% waste foundry sand (WFS) in clay bricks	3.3 MPa	Bricks classified as Class III, suitable for single-storied load-bearing structures.
[7]	20% M-Sand incorporated	2.81 MPa	Tested as per BIS standards, gradual increase in strength with fly ash addition.
[26]	15% quarry dust replacement in sandcrete blocks	3.8 MPa to 4.0 MPa	Optimal strength found at 15% sand replacement with quarry dust.
[27]	90% sand and 10% hydrated lime	21.96 MPa	Highest strength without coal tailings, lower with replacement.
[28]	Sand with industrial/agro waste (sugarcane bagasse ash, marble dust)	2.30 MPa to 3.05 MPa	Statistical study of strength variations in alternative materials
[29]	Sand replaced with 2.5%-3.5% HDPE	12.5 MPa to15.9 MPa	Highest strength at 3.0% HDPE (≈15.9 MPa); 2.5% and 3.5% HDPE give ≈12.5–12.6 MPa, all above basic load-bearing brick requirements.

Recycled Plastic			
Reference	Material Composition	Compressive Strength (MPa)	Notes
[30]	PET fibers added at 0.1%, 0.3%, and 0.5% by weight of cement	Reduced by 25% to 72% compared to conventional concrete	Strength decreases with higher PET content, though 0.5% PET fibers yielded better performance.
[37]	Self-compacting concrete with recycled plastic aggregates and industrial waste ashes	15–60 MPa (dataset range; ML model max error ≈5.46 MPa)	Predictive modeling used to estimate compressive strength trends.
[31]	PET, HDPE, and PP as partial coarse aggregate replacement at 10-30%	Reduction in compressive strength observed	Minimum reduction with PET + PP at 10%, maximum with HDPE + PP at 30%.
[34]	Self-compacting concrete with plastic fibers	Lower strength than conventional SCC	Some plastic mixes showed acceptable performance for non-structural applications.
[39]	Recycled plastic as coarse and fine aggregates	Strength varies depending on plastic type and replacement ratio	Requires optimization for structural applications.
[35]	Self-compacting concrete with plastic fibers from waste bottles	Improvement in mechanical properties at 0.5% RPF content	Excessive RPF content reduces workability and strength.
[51]	Recycled plastic aggregate and fibers used	Lower density and reduced compressive strength	Strength reduction depends on plastic type and proportion.
[36]	10% recycled plastic aggregates (RPAs)	15% decrease in compressive strength	Surface-treated RPAs minimized reduction to only 5%.
[38]	Sustainable concrete with recycled plastic aggregates	≈20–40 MPa (best mixes; plastic <25 kg/m^3)	Machine learning approach identified key factors influencing strength.

Crushed Glass			
Reference	Material Composition	Compressive Strength (MPa)	Notes
[40]	15% crushed glass replacing sand	34.54 MPa	Peak strength observed at 15% substitution.
[41]	30% fine aggregate replaced with crushed glass	6% higher than control	Strength increased up to 30%, then declined.
[42]	Waste bricks with 20–40% CG	54.85% higher than clay bricks	Met SANS 227 requirements for load-bearing use.
[44]	Sand stabilized with 10–50% CG + 10% cement	70–244% increase in shear/compressive strength	Soil stabilization with notable strength gain.
[43]	10–25% crushed glass as sand replacement	22.5–29.3 MPa	Peak strength at 15–20% glass inclusion.
[52]	20% CG as fine aggregate	Higher than control (exact not specified)	Strength drops at >30% CG.
[45]	15% CG in low-plasticity clay	Optimum UCS observed	Improved strength and stiffness at 15%.

Load-Bearing Capacity

Sand-based bricks demonstrate strong load-bearing performance, particularly when stabilized with cement or clay. Unburnt clay bricks with 4–10% cement and quarry dust achieved compressive strengths ≥10 MPa, meeting SLS 39:1978 standards for structural use [53]. Cement-clay interlocking bricks (CCI) reinforced with cement-sand mortar and CFRP composites showed up to 171% higher load-bearing capacity compared to unreinforced units [54]. These findings emphasize the role of optimized mix designs and reinforcement in enhancing structural capacity for sustainable masonry applications.

Recycled plastic, when reinforced and used in structural or geotechnical systems, also delivers substantial load-bearing strength. Recycled Plastic Pins (RPPs) achieved individual capacities of 50–207 kN, and up to 477 kN when grouped, demonstrating strong potential for soil reinforcement and lightweight foundations [55]. In embankments, RPPs paired with geosynthetics reduced settlement by 84% and bore 78% of the total load [56]. Structural elements such as railway sleepers made from recycled HDPE composites with silica fume and slag met performance standards under flexural and impact testing [57]. Recycled plastic aggregates in granular column foundations improved vertical load capacity by 47–93%, and up to 123% when encased with geosynthetics [58].

Crushed glass (CG), when blended with soils or masonry materials, has also demonstrated strong potential to enhance load-bearing capacity due to its angular shape, silica content, and pozzolanic activity. In geotechnical applications, 5–15% CG added to construction and demolition waste improved subgrade bearing pressure by up to 52%, especially at 400 mm thickness [59]. In soft soils, 8% glass powder yielded optimal CBR gains [60]. while 25% glass waste mixed with kilned expansive soil increased unconfined compressive strength from 216 to 910 kPa and boosted CBR from 0.95% to 12.08% after 14 days [61]. In masonry applications, bricks with 20–40% recycled crushed glass and PET improved compressive strength by 54.85%, meeting SANS 227 load-bearing standards [42]. These findings affirm crushed glass as a viable additive in both structural and geotechnical systems to boost load resistance and promote sustainability, as shown in Table 2.

Table 2. Load-bearing capacity of sand and recycled plastic, and crushed glass.

Sand				
Study Reference	Brick Type/Condition	Stabilizer	Load-Bearing Capacity	Notes
[53]	Cement-stabilized unburnt clay bricks with sand	4–10% Cement	≥10.0 MPa	Met SLS 39:1978 standard for load-bearing walls
[54]	Cement clay interlocking bricks (CCI)	CS mortar + CFRP	+171% from control	Load capacity significantly enhanced by dual strengthening approach

Recycled Plastic				
[55]	Foundation reinforcement	Single RPP (10–30 cm size)	50–207 kN	Grouped RPPs reached up to 477 kN
[56]	Embankment over soft soil	RPP with Load Transfer Platform	RPPs carried 78% of embankment load	Settlement reduced by 84%
[57]	Railway sleeper	RHDPE + SF + FS + CC composite	Met railway track loading standards	Durable under dynamic rail loads
[58]	Ground improvement (granular column)	Recycled plastic granules	Load capacity increased by 47–93%	Encasement led to up to 123% increase

Crushed Glass				
[59]	Subgrade stabilization	CDW + 5–15% CG	Plate Load Test	+21–52% Bearing Pressure
[60]	Soil stabilization	Soft soil + 4–12% Glass Powder	CBR	Optimal CBR at 8% CG
[61]	Stabilized expansive soil	Kilned soil + 25% CG	UCS: 910 kPa, CBR: 12.08%	CBR increased from 0.95%
[42]	Masonry bricks	20–40% RCG + PET	Compressive strength	+54.85% vs. clay bricks

Overall, these results indicate that glass- and plastic-modified systems can achieve load-bearing capacities that satisfy relevant masonry and geotechnical standards at the element scale, especially when mixes and reinforcements are optimized [10, 40, 42, 44, 48]. However, most recycled plastic data relate to applications such as reinforcement pins, railway sleepers, or ground improvement rather than brick units and full masonry walls [48, 55, 57, 58]. This imbalance highlights the need for systematic load-bearing tests on brick assemblies incorporating significant plastic and glass content under realistic service conditions [42, 48, 62].

Durability

Durability is essential for evaluating the long-term performance of sustainable bricks, particularly their resistance to moisture, chemical exposure, and cyclic weathering. Sand-based bricks made with M-sand, granite dust, or spent foundry sand exhibit reduced porosity, lower water absorption, and improved efflorescence resistance. Granite dust bricks recorded only 7.14% water absorption [47], while M-sand formulations met IS water absorption limits (<20%) [47]. Stabilized spent foundry sand also contributes to durability and thermal stability, despite potential leaching risks, due to its high silica content [63].

Recycled plastic offers sustainability benefits but poses challenges under environmental stress. Poor matrix bonding, moisture sensitivity, and thermal mismatch lead to durability loss over time. Wood plastic composites (WPCs) experienced 2–30% strength reductions after freeze–thaw cycles, though carbon black additives mitigated moisture uptake and UV degradation [64]. In concrete, recycled plastic sand replacements resulted in up to 80% compressive strength loss and structural failure after freeze, thaw exposure [65]. These findings stress the need for enhanced treatments and hybrid mixes to ensure long-term resilience in non-structural applications.

Crushed glass, when used as a fine aggregate substitute, enhances durability through reduced porosity and strong chemical resistance. In M60 concrete, 30% glass replacement minimized abrasion and acid attack, forming dense, protective matrices [66]. In SCC, 40% glass replacement resulted in minimal strength loss under sulfuric and hydrochloric acid exposure and Glass's hydrophobic and chemically inert properties reduce moisture ingress and degradation [67]. Additionally, crushed automotive glass maintained freeze–thaw durability comparable to control samples [68]. Bricks made from crushed glass and melted PET showed superior chemical durability, retaining tensile strength and mass under wet–dry sulfate conditions [42], as shown in Table 3.

Table 3. Durability of sand and recycled plastic and crushed glass.

Sand				
Study / Source	Material Composition	Water Absorption (%)	Efflorescence Presence	Durability Remarks
[63]	Sand + Plastic (1:2 to 2:5 ratios)	0% – 2.82%	Nil	High durability with strong moisture resistance
[9]	Plastic + Sand bricks	< 5%	Nil to slight	Resistant to efflorescence and suitable for structural use
[47]	Granite Dust replacing Sand	7.14% – 16.61%	Not reported	Improved moisture resistance and structural strength
[11]	Sand + Plastic Bottle Waste	9.52% – 14.46%	Nil	Water absorption within acceptable limits

Recycled plastic				
Study	Material Type	Durability Test	Observed Degradation	Notable Findings
[64]	WPC from recycled PE/PP	Freeze-thaw & xenon-arc	Flexural strength decreased by 2–30%	Carbon black improved weathering resistance
[65]	Concrete with recycled plastic aggregate	Freeze-thaw	~80% loss in compressive strength; catastrophic failures	Weak interfacial bonding & thermal incompatibility
[69]	Concrete with PET & Resin8	Thermal exposure (250°C) & OPI	No significant strength loss; “Good” OPI classification	PET showed thermal stability and maintained integrity

Crushed glass			
Study / Author(s)	Glass Content (%)	Durability Test	Observed Effect
[66]	10–40%	Acid attack, abrasion, chloride penetration	Optimal performance at 30% replacement
[67]	40%	Acid resistance test	<5% weight/strength loss
[68]	10–50%	Freeze–thaw cycles	Comparable to reference concrete
[42]	20–40%	Sulfate wet-dry cycles	No mass loss

Taken together, the durability data suggest that crushed glass generally improves resistance to chemical attack, abrasion, and in many cases, freeze-thaw cycling by producing denser, less permeable matrices [66, 67, 68, 70]. Recycled plastic can reduce water absorption but may severely compromise freeze-thaw and thermal durability when the plastic–cement interface is weak, leading to cracking and strength loss [32, 34, 51, 64]. Existing studies typically investigate isolated durability indicators and seldom track how degradation mechanisms translate into residual mechanical performance of bricks or masonry walls, leaving an important gap for future work [42, 62, 65, 71].

Long-Term Performance

Long-term performance of sustainable bricks depends on hydration behavior, mechanical aging, and resilience to environmental exposure. Cement-sand bricks (CSBs) benefit from ongoing hydration, which enhances strength and structural integrity over time, making them suitable for multi-storey load-bearing applications [72]. Their low porosity and water absorption contribute to long-term durability in outdoor environments [73]. also found that sand-based subgrade composites with kiln dust and pond ash extended pavement service life by 2.07 times, confirming durability under repeated loading.

Recycled plastic materials also exhibit promising long-term behavior across construction systems. In self-compacting concrete, recycled PET fibers reduced creep and shrinkage by up to 53.3% when paired with supplementary cementitious materials [74]. Polyethylene-modified asphalt retained stiffness over time [75], while plastic-modified pavements showed improved fatigue and moisture resistance after one year of service [76]. Recycled plastic fibers further enhanced energy dissipation and post-crack toughness in fiber-reinforced cement composites [77], supporting their use in resilient construction applications.

Crushed glass enhances long-term performance through pozzolanic reactivity, which promotes cementitious bonding, matrix densification, and refined pore structure. A 15-year field study confirmed that concrete blocks with glass aggregates experienced only surface-level ASR gel formation, indicating excellent durability [70]. Laboratory studies support improved acid resistance, chloride resistance, and abrasion performance at up to 30% glass replacement [66]. Similarly, bricks with automotive glass retained strength after prolonged curing, comparable to conventional concrete [68]. These findings affirm crushed glass as a durable, chemically stable, and sustainable additive in masonry systems.

Table 4. Long-term performance of recycled plastic and crushed glass.

Recycled glass				
Study / Author(s)	Material Type	Application	Long-Term Benefit	Performance Indicator
[74]	RPET + SCM	Self-Compacting Concrete	↓ Creep (53.3%), ↓ Shrinkage (31.5%)	Enhanced deformation resistance
[75]	rPE	Asphalt Mixture	↑ Dynamic modulus with aging	Stiffness retention under LTOA
[76]	HDPE, LDPE, PP	Porous Asphalt Pavement	↑ Fatigue resistance, ↓ moisture damage	Field-tested durability
[77]	Recycled PP, PET fibers	Fiber-Reinforced Cement Composite	↑ Post-crack energy dissipation	Improved long-term mechanical behavior

Crushed glass				
Study / Author(s)	Material Composition	Long-Term Performance Indicator	Findings	Remarks
[70]	Dry-mixed concrete blocks with crushed glass	ASR resistance over 15 years	No significant internal ASR propagation	Field-tested under real environmental exposure
[66]	M60 concrete with 30% crushed glass	Acid resistance, chloride penetration, abrasion	Optimal durability at 30% replacement	Superior chemical and wear resistance
[68]	Concrete with crushed side window glass	Compressive strength over time	Comparable strength to conventional concrete	Stable mechanical performance
[78]	Hot mix asphalt with 25–50% crushed glass	Fatigue resistance, temperature stability	Enhanced fatigue resistance; lower rutting resistance	Long-term stability under traffic loading

The long-term studies reviewed show that glass aggregates can maintain good mechanical performance and limited ASR damage over more than a decade in service, while PET-based systems can reduce creep and shrinkage when appropriately combined with supplementary cementitious materials [70, 74]. Nevertheless, almost all of these investigations concern concrete blocks, pavements, or composite elements rather than brick units and full masonry walls [40, 62, 76, 78]. Long-term, field-scale monitoring of bricks and wall systems containing high levels of recycled plastic and crushed glass is still largely missing and is crucial for confident structural design [42, 62, 65].

THERMAL & INSULATION PROPERTIES

Sustainable brick production prioritizes materials and manufacturing processes that enhance thermal performance while reducing energy consumption. This section evaluates the thermal conductivity, heat resistance, and energy efficiency of sustainable bricks compared to conventional counterparts.

Thermal Conductivity of Sustainable Bricks

In the pursuit of sustainable construction materials, thermal conductivity emerges as a pivotal factor in determining the insulation efficiency of bricks. This property is profoundly influenced by both the composition and porosity of the brick matrix. Recent advancements in material science have led to the incorporation of recycled plastics, glass, and various industrial by-products into brick fabrication, thereby significantly reducing thermal conductivity. For instance, bricks infused with recycled thermoplastic polymers such as polyvinyl chloride (PVC) demonstrate markedly low thermal conductivity values ranging from 0.18 to 0.29 W/mK, which is considerably lower than that of conventional clay bricks (0.6–1.0 W/mK) [79]. This improvement is primarily due to the presence of air pockets within the plastic matrix that impede heat transfer. Similarly, cement–glass composite bricks (CGCBs) reinforced with recycled polyethylene terephthalate glycol (PET-G) exhibit thermal conductivity between 0.35 and 0.45 W/mK, benefitting from the insulating characteristics of glass waste and polymeric scaffolds [62]. Furthermore, bricks formulated with industrial waste materials such as stone dust and fly ash achieve thermal conductivities in the range of 0.25 to 0.34 W/mK, owing to the porous microstructures formed during low-temperature curing processes [80]. Collectively, these innovations underscore the potential of utilizing waste-derived materials to enhance the thermal insulation properties of bricks by introducing air voids and reducing overall material density.

Heat Resistance and Energy Efficiency

Sustainable bricks are engineered to optimize heat resistance and energy efficiency through the strategic integration of synergistic materials and innovative production methods. Thermoplastic-based bricks, composed of materials such as polyvinyl chloride (PVC) and polyethylene (PE), maintain their structural integrity at elevated temperatures ranging from 70°C to 90°C, rendering them suitable for application in regions subject to extreme thermal conditions [79]. Additionally, cement–glass composite bricks exhibit 15–20% lower heat absorption rates compared to conventional fired bricks, effectively minimizing indoor temperature fluctuations and improving thermal comfort [62]. The incorporation of agricultural residues, particularly rice husk ash, further enhances the fire-resistant properties of sustainable bricks. During combustion, these residues form silica-rich protective layers that act as thermal barriers, thereby delaying heat penetration [71]. Beyond material composition, energy efficiency is also achieved through advancements in brick manufacturing processes. Techniques such as the use of solar-powered kilns and low-temperature curing contribute to a reduction of embodied energy by approximately 30–40% relative to traditional high-temperature firing methods [81]. These integrated approaches collectively reinforce the role of sustainable bricks as a viable solution for energy-conscious and climate-resilient construction.

Comparative Study with Conventional Bricks

A systematic comparison reveals the superiority of sustainable bricks in thermal performance as referenced to Table 5.

Table 5. Comparison of Thermal and Environmental Properties of Sustainable Bricks and Conventional Clay Bricks.

Property	Sustainable Bricks	Conventional Clay Bricks
Thermal Conductivity	0.18–0.45 W/mK [62], [79], [80]	0.6–1.0 W/mK [79], [81]
Heat Resistance	Up to 90°C (thermoplastics) [79]	Degrades above 80°C [71]
Embodied Energy	30–50% lower [62], [81]	High due to fossil fuel firing [81]
Material Source	70–90% recycled content [62], [80]	Virgin clay, no recycling [81]

Sustainable bricks have demonstrated considerable potential in enhancing energy efficiency through superior thermal performance, as evidenced by recent empirical findings. Stone waste fly ash (SWFA) bricks exhibit thermal conductivity as low as 0.25 W/mK, approximately 60% lower than that of conventional clay bricks, thereby significantly reducing heat transfer within building envelopes. Likewise, bricks composed of thermoplastic polyvinyl chloride (PVC) have been shown to lower building cooling loads by 25–35%, contributing to reduced energy consumption for indoor climate regulation [79], [80]. These metrics underscore the strategic role of sustainable bricks in minimizing the operational energy demands of buildings, aligning with global objectives to achieve net-zero carbon emissions. By integrating recycled constituents and leveraging advanced manufacturing techniques, sustainable bricks offer a dual benefit of environmental mitigation and enhanced thermal performance across diverse climatic conditions. To maximize their impact and scalability, future research should emphasize the development of standardized production methodologies and closed-loop recycling systems, which are essential for facilitating widespread adoption in the construction industry.

ENVIRONMENTAL IMPACT

The transition to sustainable brick production represents a critical response to the environmental challenges posed by traditional clay-based manufacturing. By integrating recycled materials like plastic, glass, and industrial by-products, these innovations address resource depletion, waste accumulation, and greenhouse gas emissions while maintaining structural integrity. Below, we analyze the environmental implications of sustainable brick production through three key lenses.

Reduction in Plastic and Glass Waste Through Brick Manufacturing

The incorporation of post-consumer plastic and crushed glass into brick formulations represents a significant advancement in sustainable waste management, directly addressing the growing challenges of landfill accumulation and marine pollution. Bricks composed of 20–75% recycled plastics, such as low-density polyethylene (LDPE) and polyethylene terephthalate (PET), are capable of sequestering approximately 1.5–1.7 kg of plastic waste per unit [82]. This not only reduces dependence on virgin clay and sand but also eliminates the need for water in the manufacturing process, while enhancing compressive strength by up to sevenfold compared to conventional bricks [82]. In parallel, the substitution of natural sand with crushed glass derived from post-consumer bottles, ranging from 50% to full replacement, prevents microplastic leaching and mitigates the high energy demands typically associated with glass remelting. Additionally, the integration of industrial by-products, such as foundry dust (up to 75% in Rhino Bricks) and construction and demolition debris (up to 90% in K-BRIQ), exemplifies a waste-to-resource synergy that diverts an estimated 8–15 million tons of construction waste from landfills annually. Collectively, these innovations underscore the role of sustainable bricks in fostering circular economy practices within the construction sector.

Conservation of Natural Sand Resources

Sustainable brick production offers a strategic response to the escalating depletion of natural sand, a finite resource increasingly threatened by unsustainable extraction practices. Through the adoption of alternative aggregates such as brick waste, sand, and crushed glass, up to 50% of natural sand in mortar formulations can be effectively replaced without compromising material integrity. In fact, such substitutions have demonstrated compressive strength enhancements ranging from 12% to 18% after a standard 28-day curing period [83]. Moreover, hybrid brick compositions incorporating quarry dust (10%), manufactured sand (M-sand, 10%), and recycled plastic (20%) have exhibited a 14–22% reduction in water absorption relative to conventional red bricks, thereby improving structural durability under humid environmental conditions. In addition to performance gains, these sustainable practices significantly reduce the extraction of mined clay and sand by as much as 30–50%, thereby preserving riverbed and quarry ecosystems. This reduction in resource exploitation helps mitigate soil erosion and habitat degradation, aligning brick manufacturing with broader goals of ecological conservation and sustainable resource management [81, 83].

Carbon Footprint and Environmental Sustainability

Life cycle assessments (LCAs) underscore the substantial environmental benefits of sustainable brick production, particularly in terms of emissions reduction and energy efficiency. The adoption of biomass-fired kilns and solar-powered manufacturing systems has been shown to reduce energy consumption by 40–60%, while the elimination of high-temperature firing processes, typically requiring up to 1,100°C, results in a 95% reduction in carbon dioxide emissions, as exemplified by products such as K-BRIQ [81]. Material substitutions further contribute to climate impact mitigation; for instance, the use of 100% recycled glass sand in place of conventionally processed sand avoids approximately 24.7 kg of CO_2 equivalent per ton of bricks. Similarly, bricks composed of epoxy and polyethylene terephthalate (PET) composites exhibit an 18% lower global warming potential (GWP) relative to standard formulations. Moreover, each ton of plastic-enhanced bricks diverts significant waste from incineration and minimizes cement demand in mortars, offsetting an estimated 3.2–4.1 tons of CO_2 equivalent [84]. These findings illustrate how sustainable brick production embodies a systemic shift toward circular material flows, achieving both environmental and functional advancements. By emphasizing waste valorization, resource optimization, and the deployment of low-carbon technologies, these practices support broader global sustainability objectives while addressing critical challenges within the construction sector [84].

APPLICATIONS AND CASE STUDIES

The adoption of sustainable bricks has gained traction globally, driven by the urgent need to address environmental challenges in the construction industry. This section outlines successful implementations, comparative analyses, and challenges associated with sustainable bricks, supported by case studies and references to innovative practices.

Successful Implementation of Sustainable Bricks in Construction

The practical application of sustainable bricks across a range of construction sectors highlights their growing acceptance, versatility, and environmental efficacy. In residential developments, Kenoteq's K-BRIQ, comprising 90% recycled construction and demolition waste, has been successfully implemented in urban housing projects. These bricks significantly reduce carbon emissions while minimizing dependence on virgin raw materials, thereby supporting broader net-zero carbon targets. In the commercial sector, Forterra's Eco stock bricks have gained widespread use due to their low embodied carbon value of 171 $kgCO_2e$ per tone and their certification under the BES 6001 sustainability standard. These attributes make them a preferred choice for developers prioritizing environmental compliance and performance. In public infrastructure projects, Biomason's bioLITH tiles have been employed for their recyclability and alignment with the rigorous criteria of the Living Building Challenge, a benchmark for regenerative building practices. Collectively, these case studies underscore the viability and scalability of sustainable bricks across diverse construction contexts, reinforcing their role in advancing environmentally responsible and performance-driven built environments.

Comparative Analysis of Traditional and Sustainable Bricks

A detailed comparison between traditional clay bricks and sustainable alternatives underscores the latter's advantages as referred to in Table 6.

This analysis reveals that sustainable bricks outperform traditional options in terms of environmental impact, cost efficiency, and durability while maintaining structural integrity.

Table 6. Comparison of traditional bricks and sustainable bricks across key aspects.

Aspect	Traditional Bricks	Sustainable Bricks
Material Composition	Clay, sand, water	Recycled plastic, crushed glass, industrial waste [85]
Environmental Impact	High resource depletion; CO_2 emissions	Waste reduction; low-carbon manufacturing
Durability	Moderate resistance to moisture	Enhanced durability; lower water absorption [85]
Energy Consumption	High-temperature firing (up to 1,100°C)	Energy-efficient processes; reduced firing
Cost Efficiency	Relatively expensive due to raw material costs	Cost-effective due to recycled material use [85]

Challenges and Future Research Directions

Despite sustainable bricks' promising environmental and functional benefits, several critical challenges impede their widespread adoption and commercialization. One of the primary concerns is material consistency, as the inherent variability in post-consumer plastics and crushed glass can compromise the quality and performance of the final product. Addressing this issue necessitates the implementation of advanced sorting and preprocessing technologies to ensure uniformity in feedstock composition [85]. Furthermore, the current production of sustainable bricks is predominantly limited to small-scale operations, restricting their availability for large-scale construction projects. Significant investment in automation and scalable manufacturing infrastructure is required to overcome this barrier. Compliance with regulatory frameworks also presents a hurdle, as sustainable bricks must meet stringent building codes and certifications to ensure safety, durability, and performance equivalence with conventional materials. Additionally, limited market awareness among architects, developers, and policymakers continues to hinder adoption. Targeted educational initiatives and promotional campaigns highlighting the environmental advantages of sustainable bricks could foster greater acceptance within the construction industry. Future research should prioritize the optimization of material formulations, advancement of production technologies, and the resolution of regulatory and market-related barriers. By doing so, sustainable brick solutions can transition from niche innovation to mainstream practice, playing a pivotal role in reducing construction-related waste and contributing to global sustainability objectives.

CONCLUSION

This mini-review has comprehensively examined the use of recycled plastic and crushed glass in the development of sustainable bricks, highlighting their potential to revolutionize conventional masonry materials. Recycled plastic contributes significantly to thermal insulation, water resistance, and lightweight construction, while crushed glass enhances compressive strength, mechanical integrity, and chemical durability. Together, these materials not only fulfill structural performance requirements but also contribute to environmental conservation by diverting plastic and glass waste from landfills, conserving natural sand resources, and reducing the carbon footprint of brick manufacturing. Empirical data show that optimized proportions, such as 10–15% recycled plastic or 20–30% crushed glass, can yield bricks with superior or comparable mechanical properties to conventional clay bricks. Furthermore, these sustainable bricks demonstrate resilience in long-term performance, mechanical stability, and energy efficiency. Despite challenges related to material variability, fire resistance, and standardization, the findings underscore a promising trajectory toward integrating circular economy principles into the construction sector. Continued research into hybrid formulations, large-scale production methods, and regulatory frameworks will be crucial in accelerating the adoption of eco-friendly bricks as mainstream construction materials.

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