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A comprehensive review of the physico-mechanical properties of masonry units incorporating municipal solid waste

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The growing demand for sustainable construction materials and the urgent need for effective municipal solid waste (MSW) management have led to the exploration of MSW incorporation into masonry unit production. This review critically evaluates various MSW-derived materials, including paper sludge, food waste, plastics, rubber, leather, and glass waste, in fabricating bricks and blocks. The study compares data from numerous case studies, examining how MSW integration affects physico-mechanical properties such as bulk density, compressive, tensile, flexural strength, thermal conductivity, water absorption, and porosity. The findings indicate that while including MSW often reduces density and improves thermal insulation, it can negatively impact mechanical strength beyond certain thresholds. Thermal conductivity values in MSW-based bricks were decreased significantly across a wide range of waste types, achieving values as low as 0.17 W/mK, demonstrating enhanced insulating capabilities that support energy-efficient building design. However, with optimized mix proportions and processing techniques, many MSW-based masonry units meet or exceed performance standards for specific structural and non-structural applications. This review underscores the need for further research into waste compatibility, long-term performance, and standardization to enable large-scale adoption of MSW-based construction materials.

KEYWORDS

municipal solid waste, waste management, sustainable construction, masonry bricks, building materials, circular economy, waste utilization, physico-mechanical properties

1 Introduction

Municipal solid waste (MSW) management is a critical aspect of urban sustainability, addressing the challenges posed by households and businesses' increasing volume of waste (Azevedo et al., 2021). With ongoing economic development and improved living standards, the volume of MSW generated annually in the United States has shown significant changes over time (Ashraf et al., 2019), as illustrated in Figure 1. MSW encompasses various materials that households, businesses, and institutions discard, including food scraps, packing, and other everyday items

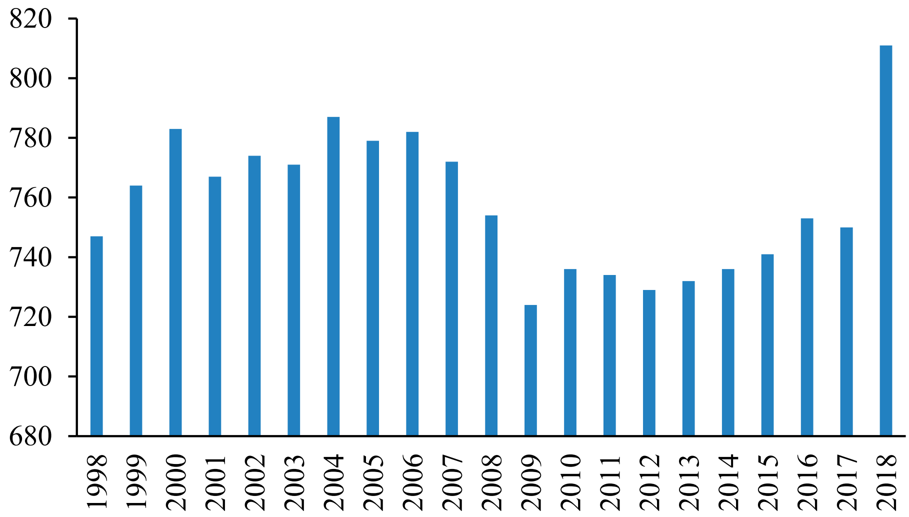

FIGURE 1
MSW generation trends in the United States (1998–2018) source: the OECD (Organization for Economic Co-operation and Development).

(Silva de Souza Lima Cano et al., 2022). Effective MSW management encompasses multiple processes, including waste collection, recycling, and disposal, which are essential for minimizing public health risks and environmental impacts (Nanda and Berruti, 2021a). The goal is to minimize environmental impact while maximizing resource recovery (Cremiato et al., 2018). Key strategies involve reducing waste generation at the source, promoting recycling and composting, and ensuring safe disposal methods such as landfilling and incineration (Mohanty et al., 2022). Recent studies emphasize integrating waste management with urban planning to enhance efficiency and sustainability (da Silva et al., 2019).

The construction industry is one of the most significant contributors to greenhouse gas emissions, so integrating sustainable practices into MSW management is increasingly important (Zhong et al., 2021). The shift towards sustainable construction materials is driven by the need to reduce the carbon footprint associated with traditional building practices, which often rely heavily on resource-intensive materials like concrete and steel (Khan and McNally, 2023).

Conventional brick and block production is a well-established method that utilizes raw materials such as clay, sand, and cement (Murmu and Patel, 2018). Production typically involves several stages: raw material preparation, mixing, molding, drying, and firing. Each stage is crucial for ensuring the quality and durability of the final products (Yuan et al., 2018). The brick and blocks produced are essential for various construction applications, providing structural integrity and aesthetic value (Hao et al., 2024). However, the traditional methods often lead to significant environmental concerns, including high energy consumption and carbon emissions from firing processes (Zhang et al., 2018). The need for sustainable alternatives has led to increased interest in incorporating recycled materials, particularly those derived from MSW, into brick-and-block production (Himabindu et al., 2024). This integration not only addresses waste management issues but also contributes to the development of eco-friendly construction materials (Soni et al., 2022). The potential of utilizing MSW in brick-and-block production is significant (Zheng et al., 2017). By recycling waste materials, the construction industry can reduce its reliance on virgin resources, lower production costs, and minimize environmental impacts (Lizárraga-Mendiola et al., 2022). Incorporating MSW into construction materials can help divert waste from landfills, reduce greenhouse gas emissions, and promote a circular economy (Ahmed, 2023; Cho et al., 2022). This approach aligns with global sustainability goals and offers a viable solution to the pressing challenges of waste management and resource depletion (Bengtsson et al., 2018).

The objectives of this review are to comprehensively analyze the utilization of MSW in brick and block production, assess the mechanical properties and environmental and economic benefits of this approach, and identify the challenges and opportunities associated with its implementation. The scope of the study includes a thorough examination of existing literature, case studies, and current practices in the field. The significance of this research lies in its potential to contribute to sustainable construction practices, enhance waste management strategies, and promote the adoption of innovative materials that can help mitigate the environmental impact of the construction industry.

2 Methodology

The literature review conducted in this study presents a comprehensive analysis of MSW utilization in brick and block production. As shown in Figure 2, our systematic search strategy encompassed multiple MSW types, using targeted databases (Google Scholar, Scopus, and ScienceDirect) with specific keywords and search contexts to ensure thorough coverage.

Using VOSViewer software to analyze references from these databases, we methodically evaluated research published in 2015–2024. The generated visualization (Figure 3) reveals several interconnected research clusters centered around the

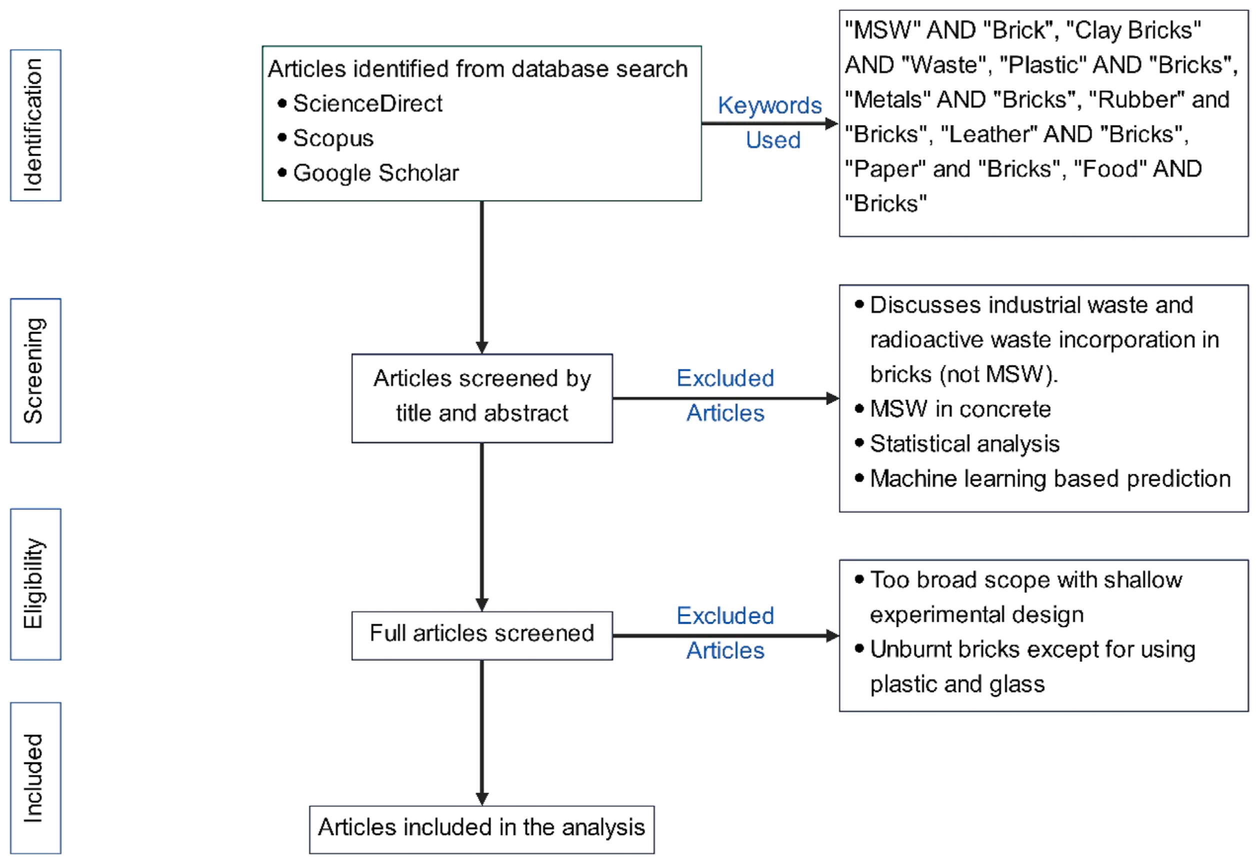

FIGURE 2
Flowchart for the identification of literature in the review.

topic of compressive strength of bricks, with significant nodes in thermal conductivity, sustainability, and material properties. Consider breaking this into shorter sentences for better readability (1) a pavement construction cluster (red) centered around "cement", "pavement blocks", and "density", representing structural applications research; (2) a sustainability manufacturing cluster (orange) focusing on "fired clay bricks", "sustainability", and "environmentally friendly" processes, highlighting eco-conscious production methods; (3) a recycling optimization cluster (yellow) dominated by "recycling", "clay bricks", "kaolin", and "paper sludge", showing waste material utilization research; (4) a plastic waste integration cluster (blue) related to "plastic waste", "plastic brick", and "construction material", indicating polymer-based research directions; (5) a concrete building cluster (green) involving "concrete bricks", "crumb rubber", and "building" applications, representing composite material studies; and (6) a thermal insulation cluster (purple) emphasizing "thermal insulation" and "alkaline activation" processes. The network mapping reveals that "compressive strength" and "thermal conductivity" serve as the two central research hubs, with extensive interconnections linking mechanical performance to thermal properties and sustainability aspects. The analysis identified critical research gaps, particularly in:

- The integration of multiple waste types
- Hazardous waste safety protocols
- Organic waste optimization
- Economic feasibility studies for large-scale implementation

The network mapping also highlights emerging research directions in eco-friendly binding materials, innovative waste pre-processing methods, life cycle assessments, and performance enhancement techniques. These findings illustrate the current state of knowledge and areas requiring further investigation in MSW-incorporated construction materials, providing a foundation for future research in sustainable building materials.

3 MSWs in construction

MSW is usually called refuse or waste. In 2018, the United States produced 292.4 million tons, representing an increase of around 23.7 million tons compared to 2017 of MSW. MSW comprises organic materials, including paper, cardboard, food, yard trimmings, plastics, and inorganic materials such as metal and glass. Figure 4 illustrates the composition of MSW produced in the United States in 2018.

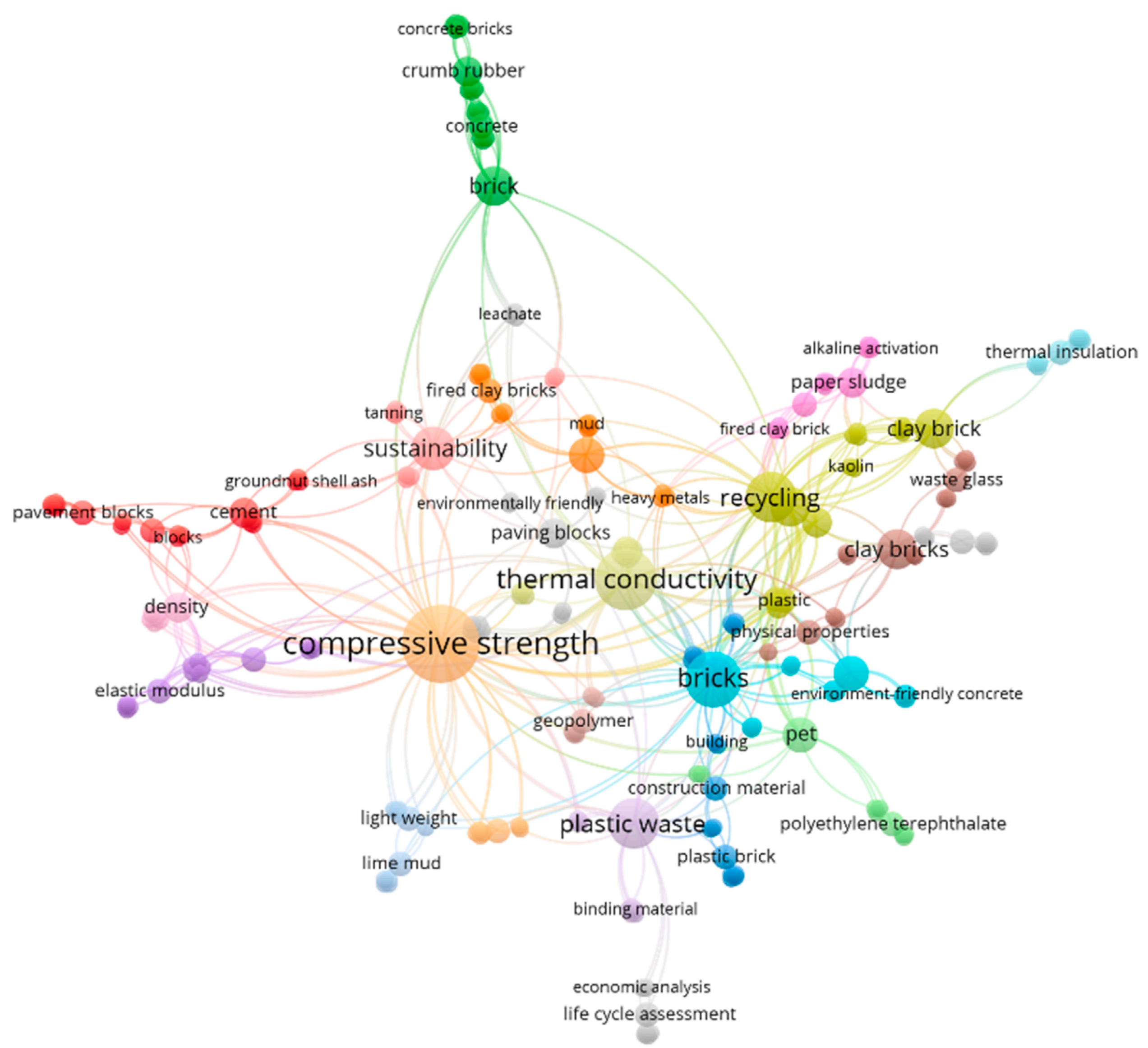

FIGURE 3
Current state of the literature in the utilization of MSW in bricks making.

The composition of MSW in the Kingdom of Saudi Arabia (KSA) exhibits various components, as depicted in Figure 5. Organic materials represent the predominant segment of the waste stream, comprising 40.5% of the total MSW generated. A notable percentage of plastics constitutes 5.2%, underscoring the ubiquity of plastic trash in the nation. Wood trash constitutes 8.0% of the total, and glass accounts for 4.6% of the waste composition. Textiles constitute 6.4% of MSW, signifying a significant presence of fabric and apparel in the waste stream. Metals and minerals constitute 8.3% of the waste, indicating the disposal of diverse metallic and mineral-based products. Notably, 2.0% of the waste is categorized as others, including items that do not fit into the primary classifications. Analyzing MSW composition in Saudi Arabia offers critical information for waste management strategies and prospective recycling activities, especially considering the substantial proportion of organic waste and the notable availability of recyclable materials, including plastics, metals, and glass. Figure 6 provides an overview of the references used for each type of MSW.

Paper and paperboard (PPB) products constitute one of the main components of MSW. PPB mainly consists of lignin, cellulose, and hemicellulose (lignocellulose) (Gonzalez-Estrella et al., 2017). Food waste (FW) primarily originates from households, restaurants, cafeterias, processing enterprises, and markets (Lv et al., 2021). Global industrial production of plastics has risen by around 80% since 2002. Plastics are categorized into seven primary types based on their recyclability: polyethylene terephthalate, high-density polyethylene, polyvinyl chloride, low-density polyethylene, polypropylene, polystyrene, and miscellaneous plastics (Nanda and Berruti, 2021b). In the United States, tree debris is classified as MSW known as "yard trimmings," including grass, leaves, and brush. In 2017, the estimated national generation of yard trimmings was 31.9 million tons, constituting approximately 13.1% of total

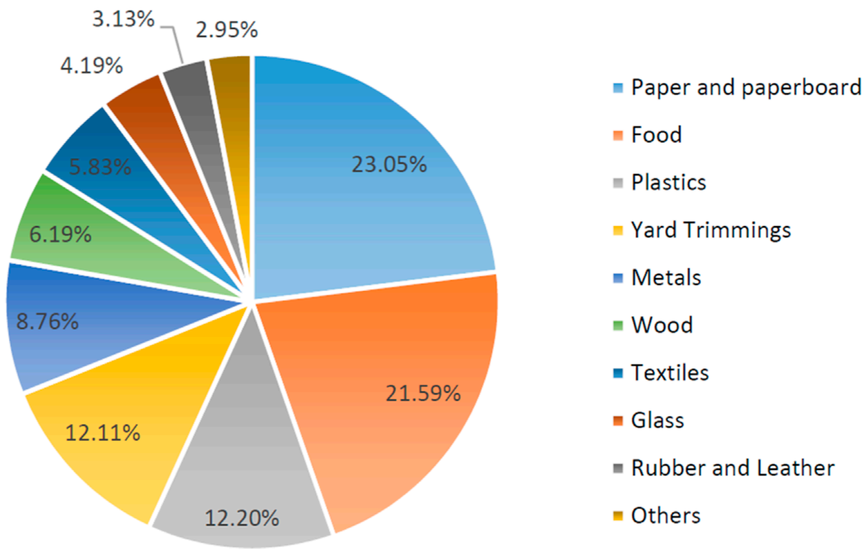

FIGURE 4
Distribution of MSW produced in the United States in 2018. 292.4 Million Tons (Before Recycling). Source: Environmental Protection Agency (EPA), https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview.

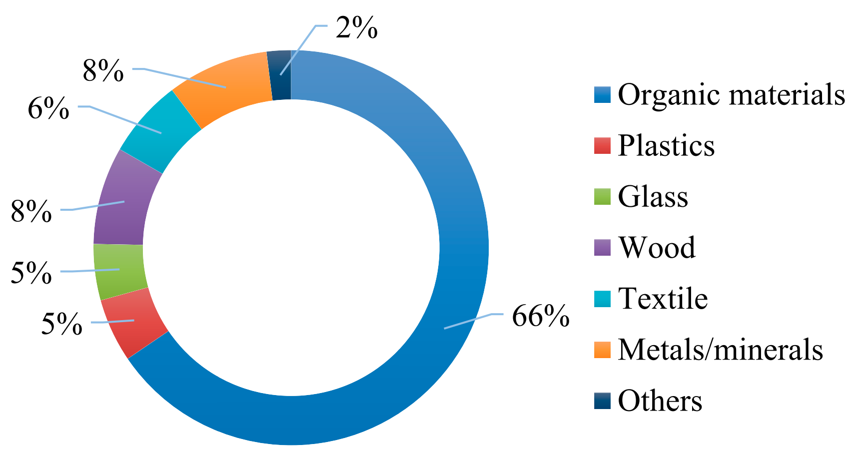

FIGURE 5
Composition of MSW produced in KSA.

municipal solid garbage (Schmitt-Harsh and Wiseman, 2020). The concentrations of six heavy metals, namely Zn, Cu, Mn, Pb, Cr, and Cd, diminished in all the simulated landfills (Wang et al., 2021). Ferrous metals (iron and steel) are the predominant group of metals in MSW by weight. The principal sources of ferrous metals in MSW are durable products, including appliances, furniture, and tires. Containers and packaging represent an additional source of ferrous metals in MSW (Ghanbarzadeh et al., 2024). Wood sources in MSW comprise furniture, durable goods (such as cabinets for electrical devices), wood packaging (including crates and pallets), and various miscellaneous items (Aziz et al., 2021; Teacă et al., 2023). Nonetheless, as indicated by Indhiradevi et al. (2020), the wood ash utilized in this investigation was not sourced from MSW but from combustion procedures, which are especially intended for ash production for construction applications. Additionally, other research has examined the application of wood ash, not derived from MSW, in manufacturing bricks and blocks, emphasizing its capacity to enhance strength, diminish environmental effects, and reduce production costs. The majority of the goods that are classified as textiles in MSW are products that have been thrown, including but not limited to rugs, footwear, sheets, and towels (Lee et al., 2023).

4 Physical properties of MSW-based masonry bricks

4.1 Bulk density

Bulk density (BD) changes due to temperature variations during testing is one of the prime concerns in eco-friendly brick

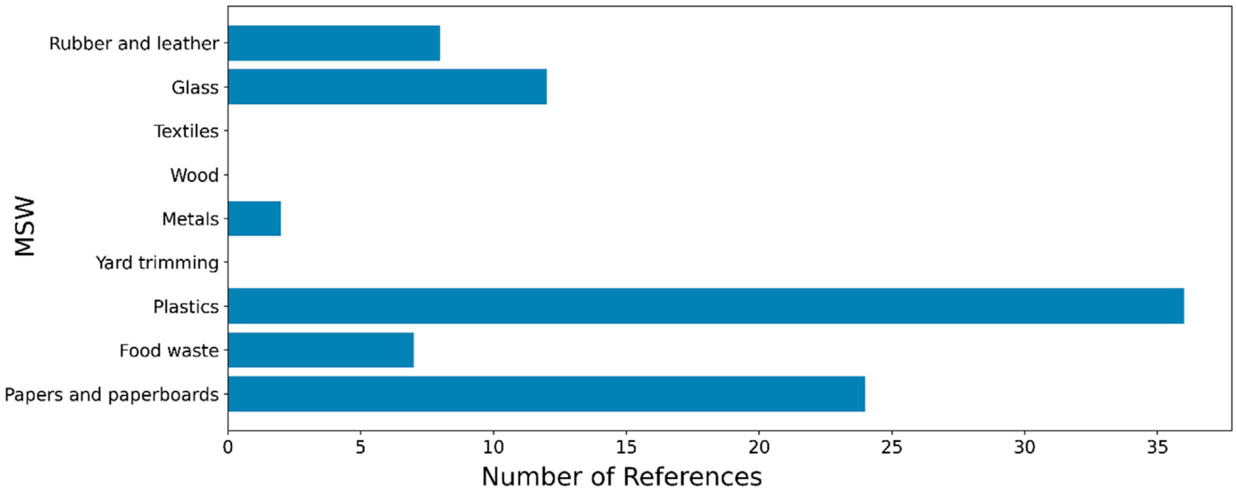

FIGURE 6
References used for different types of MSW in the literature.

manufacturing. Generally, MSW addition results in a decrease in the density of bricks. Multiple studies report density reductions following the addition of solid waste. Addition of paper mill sludge (PMS), as done by Goel and Kalamdhad (2018), noted a significant decrease in the density from 1560 to 640 kg/m^3 on inclusion of 30% sludge by weight. Similar results were drawn for other research incorporating paper mill or sludge waste. This was also inferred by Singh et al. (2018). The reduction in the density is probably due to the burning of de-inking PMS, leaving the pores behind as a residue. The addition of food waste, like tea waste (TW), also resulted in a decrease in the density of fired clay brick (Hussien et al., 2024). The density decreased from 1963.91 kg/m^3 to 1602.18 kg/m^3 on adding 0%–10% TW, respectively. Similarly, bricks made with spent oyster mushrooms as additives exhibited a reduction in density, with values decreasing from 1870 at 0% to 1370 kg/m^3 at 15% oyster mushrooms by volume, indicating that higher concentrations of organic waste contribute to a less dense structure (Chung et al., 2021).

Adding eggshell powder to waste glass-based bricks also decreased density, with bricks incorporating 5% eggshell powder showing a notable decline in density compared to the control (Tangboriboon, 2019). Furthermore, TW in fired clay bricks led to a marked reduction in BD, dropping from 1860 at 0% TW to 1580 kg/m^3 at 12% TW when the firing temperature was 1250°C and 1590 at 0% TW to 1370 kg/m^3 at 12% TW when firing temperature was 950°C, demonstrating that higher TW content reduces the compactness of the material (Ozturk et al., 2019). Similarly, the use of wine lees (WL) and grape seeds (GS) in clay bricks decreased the BD, with the values for WL ranging between 1320–1460 kg/m^3 at 10% content, while GS resulted in even lower density values of 1170–1200 kg/m^3 at the same concentration (Taurino et al., 2019). When considering plastic-based waste materials like plastic dust and high density polyethylene (HDPE), the value for BD ranged from 1654 to 1298 kg/m3 for addition of 0%–15% plastic dust by volume and 2000 to 1360 kg/m^3 on 0%–50% by volume incorporation of HDPE (Idrees et al., 2023; Sarwar et al., 2023). Introducing cassava peel bio-solid waste (CP) into clay bricks decreased density, with the lowest values observed at 16% CP, highlighting the effect of organic additives in reducing material density (Adazabra et al., 2024) Furthermore, in the case of incorporation of sago fine waste (SFW) mixed with cement decreased the density of the resulting bricks, with values dropping from 2103–2127 kg/m^3 at 0% SFW to the range of 1687–1796 kg/m^3 at 10% SFW, further emphasizing the influence of waste materials on the BD of construction materials (Norhayati et al., 2023). These findings collectively suggest that the incorporation of various waste materials into construction bricks and pellets reduces BD, which could impact the final product's structural and thermal properties.

Figure 7 illustrates the variation in BD with increasing concentrations of MSW for a diverse set of waste-derived ashes, each treated at varying calcination temperatures. A consistent trend is evident across all materials: as the MSW content increases, the BD of the composite material significantly decreases. This behavior is primarily attributed to the lower specific gravity and increased internal porosity of MSW ashes compared to conventional cementitious binders or aggregates. The porous structure of MSW-based ashes, often resulting from the combustion of organic matter and volatile components during thermal treatment, leads to a looser particle packing arrangement, thus reducing the overall density. At 0% MSW, the highest bulk densities are observed in materials like high-density polyethylene and leather buffing dust, both exceeding 2200 kg/m^3 and reaching up to 2400 kg/m^3. These materials initially offer compact and denser structures, likely due to their thermoplastic or fibrous origins, which result in tighter interparticle packing and less void content. However, as MSW increases, their bulk densities drop markedly, indicating that the incorporation of MSW disrupts the matrix and introduces greater void space. On the other end of the spectrum, waste-paper ash and oyster mushroom ash exhibit considerably lower bulk densities even at minimal MSW levels, with values falling below 1200 kg/m^3 at higher MSW concentrations. This suggests these ashes are inherently lighter and more porous, and their structural contribution in terms of density is minimal. PMS and paper pulp residue (PPR) follow a similar trend, showing significant reductions from approximately 1800–1900 kg/m^3 to below 1400 kg/m^3 as MSW percentages reach

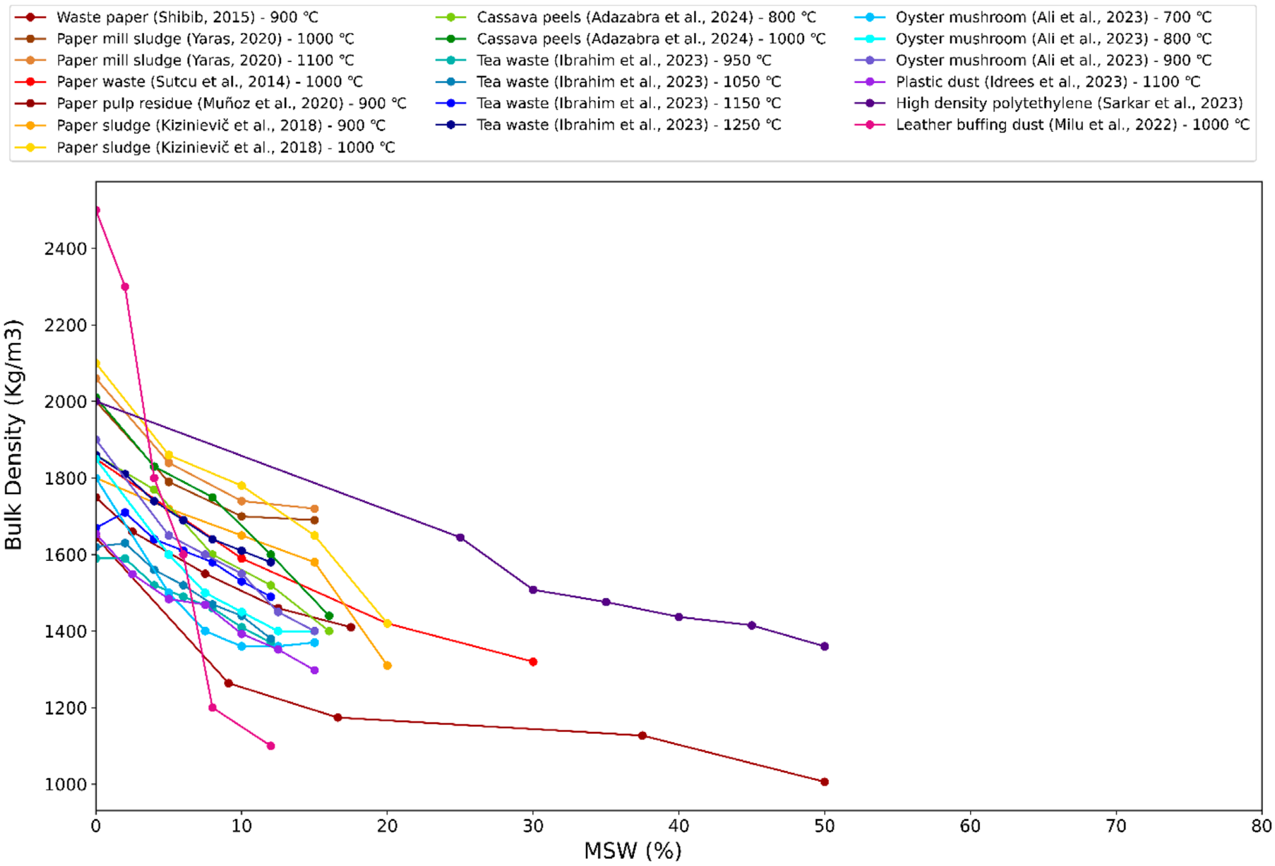

FIGURE 7
Variation of BD with addition of MSW concentration.

20%–30%. TW ash, calcined at various temperatures ranging from 950°C to 1250°C, displays a more gradual and controlled reduction in BD. This indicates that higher calcination temperatures may promote partial sintering or particle densification, which slightly stabilizes BD despite increasing MSW content. Additionally, CP ash treated at both 800°C and 1000°C demonstrates intermediate behavior, starting from moderate densities and showing a steady decrease, reflecting the influence of organic content and thermal reactivity.

Overall, the incorporation of MSW-derived ash leads to a reduction in BD across all types of waste materials, highlighting their potential application in the development of lightweight construction materials. While this property is advantageous for reducing dead loads and enhancing thermal insulation, it is critical to balance these benefits with the need to maintain acceptable levels of strength, durability, and overall performance for structural applications. The observed data supports the idea that material selection and processing temperature play a crucial role in controlling BD and tailoring mix designs to meet specific engineering requirements.

4.2 Porosity

Incorporating waste materials into construction significantly affects their porosity, often increasing the void space within bricks and pellets. For instance, bricks containing TW showed a substantial increase in porosity, with values rising from 16.14% at 0% TW to 28.87% at 10% TW (Hussien et al., 2024). This suggests that the organic nature of TW enhances the porous structure of the bricks, which may improve thermal insulation but reduce overall strength. Similarly, bricks incorporating SCG and TW also exhibited increased porosity. With SCG content rising from 0% to 10%, the porosity increased from 12.27% to 32.62%, highlighting the influence of organic waste in creating more air pockets within the material (Chung et al., 2021). In another study, eggshell powder used in waste glass-based bricks led to a higher porosity in the resulting materials, with the control brick showing a porosity of 9.47%, while the brick containing 5% eggshell powder had a porosity of 17.73%, illustrating how the addition of waste materials can create a more porous structure (Tangboriboon, 2019).

In bricks made with TW, the porosity increased as the TW percentage rose, from 25.1% at 0% TW to 33.3% at 12.5% TW, further confirming the role of organic materials in expanding the internal void spaces of the brick (Ozturk et al., 2019). Similarly, including wine lees (WL) and grape seeds (GS) in clay bricks resulted in a rise in porosity. For WL, the porosity ranged from 37.5% at 10% content to 43.9% at 20% content, while GS-based bricks exhibited even higher values, reaching up to 50.1% at 10% GS (Taurino et al., 2019). This increase in porosity will likely reduce the material's weight and potentially improve its insulation properties, though it may also affect its mechanical strength. The effect of plastic waste on porosity depends on the type of plastic and the mix design. While hydrophobic and dense plastics like HDPE and LDPE often reduce porosity when combined with other materials such as bottom ash, copper slag, ceramic or foundry sand (Monish et al., 2021; Aneke and Shabangu, 2021), others, such as plastic dust or mixed waste, as done by Subhani et al. (2024) increase the value for porosity.

4.3 Thermal conductivity

Thermal conductivity is an essential property for assessing the insulating qualities of building materials. Waste materials frequently help lower thermal conductivity, which is advantageous for energy efficiency when mixed into clay bricks or pellets. Because of their larger porosity and air pockets that act as thermal insulators, organic waste materials have been shown in numerous studies to considerably impact thermal conductivity in construction materials, usually lowering it. The incorporation of paper-based materials also influences the thermal conductivity of bricks. Waste paper and paper sludge (PS) reduce the thermal conductivity of bricks, making them more efficient as thermal insulators. For instance, PS bricks had a thermal conductivity range of 0.396–0.555 W/mK, with higher paper content leading to a lower thermal conductivity (Ospina Salazar et al., 2023) This reduction in thermal conductivity is beneficial for energy-efficient construction, as it helps maintain a stable indoor temperature. Similarly, other studies reported decreased thermal conductivity, ranging from 0.15 W/mK to 0.39 W/mK depending on the paper content and the firing temperature (Goel and Kalamdhad, 2018; Sutcu et al., 2014). Additionally, wine lees (WL) and grape seeds (GS) reduced thermal conductivity in bricks constructed with these components. While GS-based bricks showed even more notable improvements, with values as low as 0.73 W/mK at 10% GS, the thermal conductivity for WL decreased from 1.05 W/mK at 10% content to 0.84 W/mK at 20% content (Taurino et al., 2019). By increasing the bricks' porosity, these organic waste ingredients improve their insulation properties and slow the pace heat moves through them. The impact of organic waste on thermal conductivity was also noted in clay pellets. The thermal conductivity of clay pellets decreased by adding groundnut shells, coffee grinds, and cork powder. Thermal conductivity decreased from 0.68 W/mK to 0.46 W/mK in pellets containing larger percentages of groundnut shells, demonstrating the organic material's insulating properties (Cobo-Ceacero et al., 2023). A similar pattern was seen when CP biosolid was added to clay bricks; the thermal conductivity dropped from 1.02 W/mK at 0% CP to 0.92 W/mK at 16% CP, confirming the notion that waste materials might enhance the thermal performance of construction materials (Adazabra et al., 2024). The incorporation of plastic waste into construction bricks significantly impacts thermal conductivity, typically leading to a reduction due to the low thermal conductivity of plastic materials. This property enhances the insulation performance of plastic-based bricks, making them suitable for energy-efficient construction applications (Aneke and Shabangu, 2021; Alaloul et al., 2020). Also, as micro-voids serve as insulating barriers, bricks manufactured with larger percentages of plastic dust exhibit better thermal performance (Idrees et al., 2023).

4.4 Water absorption

Water absorption (WA) is another critical factor impacted by paper-based materials. Bricks with higher paper content tend to exhibit increased water absorption, which is linked to the higher porosity of the bricks. For example, bricks with PPRs demonstrated water absorption values ranging from 20% to 35%, depending on the content and curing conditions (Akinwande et al., 2021). Similarly, other studies observed 8% and 37% water absorption rates, with PS content increasing the brick's porosity and water uptake (Goel and Kalamdhad, 2018; Sarkar et al., 2017). Regarding paper waste, it has been reported that the water absorption in bricks with wastepaper inclusion is much more than that of PMS (Sutcu et al., 2014; Shibib, 2015; Yaras, 2020; Kizinievič et al., 2018a). In the case of food waste-based MSW incorporation, the value generally varied for a range of approximately 8%–15% on inclusion of 10% waste as reported by the study through TW and CP (Adazabra et al., 2024; Ibrahim et al., 2023). Due to plastic's hydrophobic nature, adding plastic trash to bricks and other building materials considerably lowers water absorption. For instance, bricks manufactured from recycled HDPE or PP plastic waste have remarkably low water absorption rates—0.752% for HDPE and 0.370% for PP (Kulkarni et al., 2022). Similarly, water absorption rates as low as 1.5%–4.9% are achieved by LDPE-based composites with bottom ash, ceramic, or copper slag, significantly lower than traditional clay bricks (Monish et al., 2021). Preserving compatibility with second-class brick standards, including plastic dust as a partial substitute for clay also keeps water absorption within acceptable bounds, with values staying below 20% even at greater plastic dust levels (Idrees et al., 2023). Conversely, leather and tannery result in comparatively less water absorption.

Figure 8 presents the variation in WA with increasing MSW concentration for a range of waste-derived ashes treated at different calcination temperatures. A clear upward trend is observed across nearly all materials, indicating that as the proportion of MSW increases, the WA capacity of composite materials also rises. This increase in WA is largely attributed to the porous and hydrophilic nature of MSW-derived ashes, which contain a high volume of micro-voids, unburnt organic residues, and loosely packed particles. These characteristics promote moisture penetration and retention, thereby increasing the overall water uptake. The most prominent increase is observed in high-density polyethylene ash, where WA exceeds 80% at 50% MSW concentration, highlighting its extremely porous and water-retentive structure. Similarly, tannery sludge ashes, particularly those treated at 900°C and 950°C, show high absorption values, surpassing 40% at higher MSW content. These results suggest that thermally treated organic-rich wastes tend to produce ashes with large pore networks, which significantly elevate capillary absorption. Waste-paper ash and plastic dust also display steep increases, indicating that these materials are less dense and contain higher internal voids, making them more susceptible to water ingress. In contrast, materials such as CPs, PS, and TW ash exhibit more moderate increases in WA with MSW addition. Their lower absorption rates, even at higher MSW percentages, suggest relatively better thermal transformation and possibly denser ash morphology. The behavior of TW ash, particularly at higher treatment temperatures (up to 1250°C), indicates that controlled calcination can improve ash quality by reducing unburnt carbon

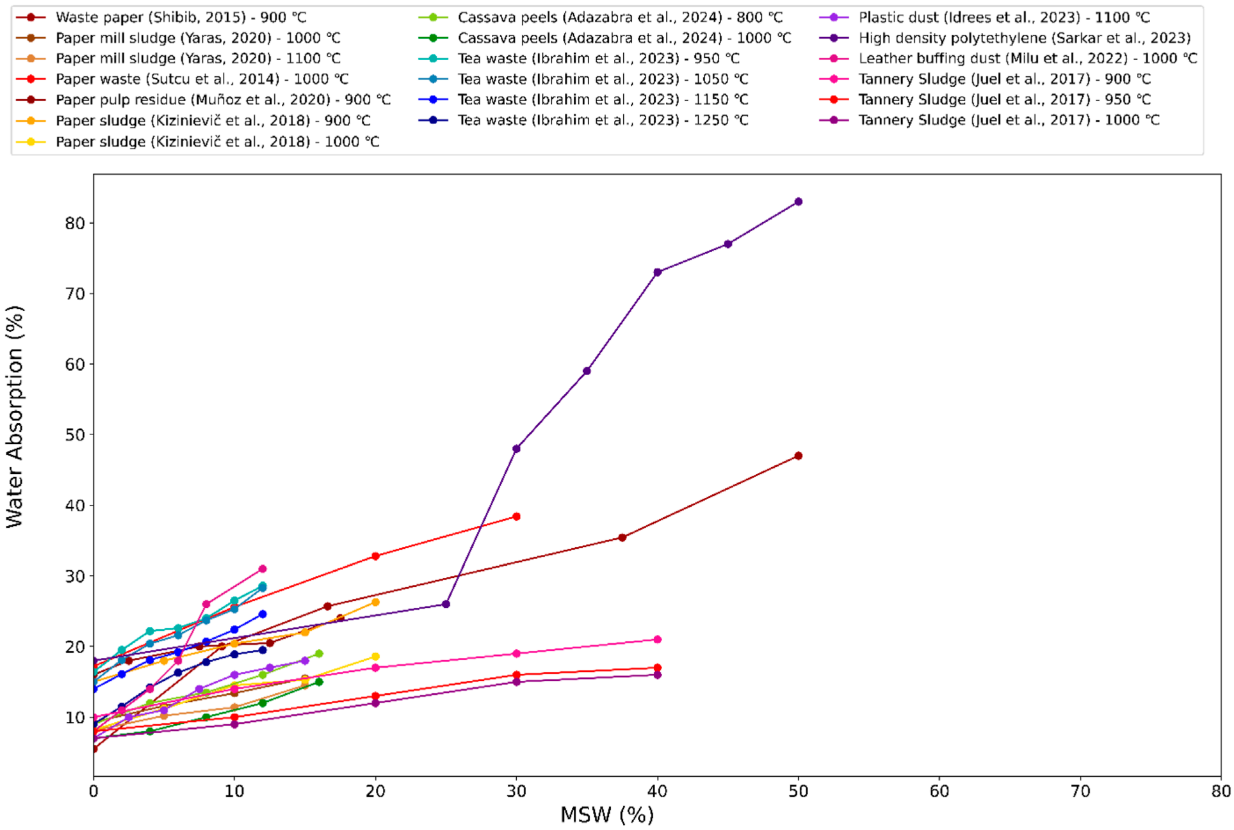

FIGURE 8
Variation of water absorption with the addition of MSW concentration.

and decreasing pore connectivity, thus restraining excessive water absorption.

Overall, the rising trend of WA with increasing MSW concentration demonstrates the influence of ash structure and composition on moisture interaction. While elevated WA may enhance internal curing in certain lightweight or non-structural applications, excessive absorption poses challenges in terms of durability, dimensional stability, and long-term strength retention. Therefore, careful optimization of MSW content and calcination conditions is essential when developing sustainable construction composites using waste-derived ashes.

5 Mechanical properties of MSW-based masonry bricks

5.1 Compressive strength

Compressive strength is deemed the most essential quality index for a brick (Shi and Zheng, 2007; Saikia and De Brito, 2012). For normal weather conditions, the minimum compressive strength of brick according to ASTM C62-13a standard is 10.3 MPa. The addition of paper-based admixtures to bricks generally results in lower compressive strength (Tables 1–5). For example, bricks made from a mixture of paper pulp (47.5%–50%) and banana fiber exhibited compressive strength values up to 6.7 MPa, significantly lower than conventional clay bricks (Akinwande et al., 2021). Similarly, other studies found that increasing paper content in brick mixtures led to decreased mechanical strength, with compressive strengths ranging from 2.4 MPa to 36.7 MPa depending on the type and concentration of paper admixture (Yaras, 2020; Sutcu et al., 2023). Notably, certain combinations of paper and other materials, such as fly ash or banana fibers, can partially offset the reduction in strength by enhancing the bonding properties of the matrix. For food waste like TW, the compressive strength tends to decrease as the percentage of waste increases. For example, bricks with 10% TW content exhibited a compressive strength reduction from 29.55 MPa (at 0% TW) to 17.71 MPa (at 10% TW), indicating that the addition of organic waste reduces the brick's overall load-bearing capacity (Hussien et al., 2024). Conversely, adding waste materials such as eggshell powder (EP) in glass-based bricks increased compressive strength. For example, adding 5% eggshell powder to waste glass-based bricks raised the compressive strength from 25.73 MPa (for the control brick) to 27.83 MPa, representing a modest improvement in strength (Tangboriboon, 2019). The control mix using glass and plastic waste achieves 40 MPa, while the 55% by mass additional of glass reduces it to 22 MPa. A combined mix of 25% glass and 2% plastic achieves a balanced 25 MPa (Zhang et al., 2022) Rauniyar et al. (2024) used polypropylene waste fibers and noted that the strength is maximum at 10% addition of waste, and reported it to be 16.85 MPa, compared to the 13.44 MPa at 5% and 12.62 MPa at 15%. Similarly, an addition of 30% SPW noted a compressive strength of 30% SPW (Aneke and Shabangu, 2021). Overall, plastic waste usage is deemed beneficial for clay brick manufacture.

Figure 9 illustrates the variation in compressive strength of bricks with increasing concentrations of MSW for a variety of waste-derived ashes treated at different temperatures. A general downward trend is observed across all materials, indicating that higher MSW content typically results in reduced compressive strength. This decline can be attributed to several factors, including the reduced binding capacity, poor particle interlocking, and increased porosity introduced by the incorporation of lightweight and organic-rich ash materials. As MSW content rises, the structural matrix becomes less compact and more heterogeneous, leading to a decrease in load-bearing capacity. Among the materials tested, leather buffing dust and high-density polyethylene initially show the highest compressive strengths, with values exceeding 45 MPa and 40 MPa respectively at 0% MSW, primarily reflecting their higher baseline control strengths rather than inherent material advantages. These materials also maintain relatively higher strengths even at elevated MSW contents, which may be attributed to their stronger initial matrix in addition to favorable particle morphology, better bonding characteristics, or partial sintering effects during calcination. In contrast, materials such as oyster mushroom ash and paper sludge exhibit significantly lower compressive strength values from the outset, which decline rapidly with increasing MSW. This suggests that these ashes may lack sufficient pozzolanic reactivity or cohesive properties to form a dense and durable brick matrix. Tannery sludge, across various temperatures (900°C–1000°C), demonstrates a moderately strong initial performance but shows noticeable reductions in compressive strength beyond 20%–30% MSW, indicating limited tolerance to high ash content. Tea waste ash, processed at different calcination temperatures, reveals varied results: while higher temperatures (e.g., 1250°C) slightly improve initial compressive strength, the overall trend still indicates a loss in strength as MSW concentration increases. Similarly, paper mill sludge and paper waste ashes follow a consistent downward pattern, with compressive strength dropping to as low as 10 MPa or below at higher MSW levels.

The normalized strength analysis reveals distinct performance categories when baseline differences are eliminated. High-density polyethylene demonstrates exceptional retention (98% at 10% MSW, 85% at 50% MSW), while most paper-based materials maintain 68%–88% of control strength at 10% MSW content. Organic waste shows moderate performance with tea waste retaining 82%–88% and cassava peels 78%–80% at 10% MSW. Conversely, paper mill sludges exhibit the steepest decline (65%–68% retention at 10% MSW), whereas leather buffing dust uniquely shows initial improvement (110% at 10% MSW) before declining. This normalized comparison eliminates baseline bias and provides unbiased material performance ranking essential for practical engineering applications.

The observed reductions in compressive strength highlight the critical need for optimizing MSW replacement levels to balance sustainability with structural performance. While incorporating waste materials supports circular economy goals and reduces the environmental footprint of construction materials, excessive MSW content can compromise the mechanical integrity of the bricks. Therefore, establishing optimal replacement thresholds and refining calcination conditions are essential for ensuring that waste-derived bricks meet the required standards for load-bearing applications.

5.2 Tensile strength

Fibrous additives like banana fiber or cellulose improve tensile properties by reinforcing the material matrix. However, porosity limits tensile performance at higher waste levels. Therefore, more porous materials often lead to less tensile strength. On the addition of 0%–12% of deinking PS (DPS), the value for tensile strength is not reported. Still, the characteristic indicated by increasing porosity reflects that the value for tensile strength will be depleted (Makni et al., 2024). At 10% TW content, the tensile strength of bricks decreased significantly from 1.45 MPa (for control bricks) to 0.85 MPa, reflecting the negative impact of TW on the material's ability to resist tensile forces (Hussien et al., 2024). This reduction is attributed to introducing porous spaces within the material, which weakens the overall matrix and makes it more susceptible to stretching and pulling. Similarly, SCG also causes a decrease in tensile strength. Bricks with 10% SCG content exhibited a reduction from 1.66 MPa to 1.10 MPa (Chung et al., 2021). The addition of such waste materials introduces micro-voids, which reduce the material's resistance to stretching forces, thus lowering its overall tensile strength. On the other hand, certain inorganic waste materials, such as EP, can enhance tensile strength when mixed with other construction materials. Adding 5% eggshell powder to waste glass-based bricks increased tensile strength from 1.60 MPa to 1.80 MPa (Tangboriboon, 2019). Meanwhile, the variability of tensile strength for clay bricks depends on the plastic type used and the particle size. PET and PU mixed waste decreased the tensile strength of clay bricks as noted by Alaloul et al. (2020). Conversely, the tensile strength increased from 7.36 MPa to 9.51 MPa, increasing the scrap plastic waste (SPW) from 20% to 30%. Subhani et al. (2024) conducted a study investigating the mixture of plastic waste, including HDPE, PET, and LDPE. They inferred that the value of tensile strength is about 1.35 times that of traditional clay bricks. This result is further supported by the results drawn from research on LDPE by Arun Solomon et al. (2023).

Overall, as shown in Tables 1–5, the impact of MSW-derived additives on tensile strength varies based on material type, porosity, and bonding characteristics. Organic wastes such as TW and spent coffee grounds (SCG) generally reduce tensile strength due to the formation of internal voids and weak matrix cohesion, with declines reaching up to 40%–50% at higher replacement levels. Paper-based residues, while not always directly measured for tensile strength, exhibit similar tendencies due to increased porosity. In contrast, certain inorganic additives like eggshell powder and scrap plastic waste have demonstrated improvements in tensile properties. For example, bricks with eggshell powder showed slight increases in tensile strength, while those with optimized levels of plastic waste exhibited significantly higher values compared to traditional clay bricks. These outcomes highlight the critical role of material compatibility, particle structure, and bonding efficiency in determining tensile performance in MSW-integrated masonry units.

5.3 Flexural strength

In most cases, waste materials improve flexural strength at lower contents by enhancing bonding and densification. Excessive content often leads to porosity increases, reducing bending resistance. On addition of recycled PS (RPS) and expanded perlite (EP), the value of flexural strength ranged from 10.2 MPa to 34.6 MPa, depending on firing conditions. The combination of RPS and EP provides strength and reduces weight while maintaining flexibility (Sutcu et al., 2023). The flexural strength value ranges from 2 MPa to 4 MPa, with higher PPR (PPR) contents moderately increasing bending strength due to the material's elasticity (Muñoz et al., 2020a). Bricks made with TW exhibited a reduction in flexural

TABLE 1 Physico-mechanical properties of masonry units incorporating MSW materials namely: Paper and Paperboard.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity	Other properties	Ref.
PS 25%, 35%, or 45%	Extruded, cut to size, then cured at room temperature for 28d	Cylinders (Ø 30 × H60) and Prisms (40 × 40 × 160)	1470–1560	CS: 14–25 FS: ~ 2–7	WA: 17%–22% Porosity: Increased by 3%–23% with PS addition	Thermal conductivity: 0.396–0.555 W/mK Flame resistance: Retained structural integrity after 1 h of direct flame exposure	Ospina Salazar et al. (2023)
PMS 5%–30%	Extrusion, pressing at 10–100 MPa, Hand molding	60 × 30 × 10 85 × 85 × 10 150 × 60 × 20 61 × 29 × 19	640–1560	CS: 2.6–43	WA: 8%–28% Porosity: Increased with increasing PMS content	Reduced thermal conductivity (0.13–0.39 W/mK) Reduced firing temperature Fuel savings of up to 3%	Goel and Kalamdhad (2018)
Paper mill waste (PMW, lime mud) 0%–40% Fly ash 0%–10%	Unburnt bricks: Hand molding, natural drying for 2 days, sun drying for 2 days, room temperature curing for 28d Burnt bricks Hand molding, conventional drying for 1 week, kiln firing	Unburnt bricks: 190 × 90 × 90 Burnt bricks: 230 × 110 × 70	—	Unburnt bricks: CS: 1.18–1.68 Burnt bricks: CS: 3.33–3.61 (up to 20% lime mud)	WA: 22%–27% for burnt bricks	Optimum PMW content for unburnt bricks with fly ash is 30% Burnt bricks show cracks when PMW content exceeds 25% PMW acts as a binder and inert filler, improving packing and densification	Sarkar et al. (2017)
Deinking PMS (DPMS) 0%–30%	Hand molding, air drying for 24 h, oven drying at 100°C for 24 h, firing in electric furnace at 900°C, 950°C and 1000°C	75 × 50 × 33 (briquettes)	1302–1821	CS: 5.82–22.55	WA: 12.34%–28.57% Porosity: 32.84%–49.42%	Linear firing shrinkage: 2.67%–3.07% Thermal conductivity: 0.245–0.551 W/mK Color changed from reddish to cream/buff with increasing DPMS content Efflorescence: Slight to moderate	Singh et al. (2018)
PPR 47.5%–50% Alkaline modified banana fiber (BF) 0%–2.5%	Mixing, molding under 5 MPa pressure, curing in water basin for 28d and 56d	400 × 100 × 100 190 × 90 × 90 100 × 100 × 100 (cubes) Cylinders: Ø 100 x H200	–	At, 56d curing CS: Up to 6.7 (for 1.5% BF) FS: Up to 0.61 (for 2.5% BF)	WA: 9.1%–35% (varies with BF content)	Moisture absorption: 7.5%–9.5% Splitting tensile strength: Up to 0.14 MPa Thermal conductivity: 0.15–0.22 W/mK	Akinwande et al. (2021)

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TABLE 1 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Paper and Paperboard.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity	Other properties	Ref.
Recycled PS (RPS) 0%–10% Expanded perlite (EP) 0%–10%	Mixing of components, extrusion molding, drying at 40°C for 24 h then 105°C for 12 h, firing at 850°C, 950°C or 1050°C for 2 h	40 × 40 × 160	1330–1770	CS: 10.2–34.6	WA: 18.5%–37.1% Apparent porosity: 32.6%–49.3%	Thermal conductivity: 0.432–0.895 W/mK Linear firing shrinkage: ~2% Optimum composition: 10% EP + 10% RPS fired at 950°C for lowest thermal conductivity (0.477 W/mK) with acceptable strength (10.2 MPa)	Sutcu et al. (2023)
Wastepaper 9.1%, 16.6%, 37.5%, and 50% by weight of wet clay	Mixing of wastepaper with wet clay, molding, drying, firing at 900°C for 10 h, cooling in furnace for 2d	105 × 100 × thickness of original brick	1006.2–1264.8	CS: 21.8–36.7	WA: 20%–47% (24-h cold water absorption) Porosity: 52%–66.3%	Thermal conductivity: 0.39–0.52 W/mK Specific heat: 598–678 J/kg·K Saturation coefficient: 0.78–0.95 Softening coefficient: 0.74–0.84	Shibib (2015)
PMS 0%–15% Carbonation sludge (CarS) 0%–30%	Mixing, pressing under 50 MPa, drying, firing at 1000°C and 1100°C	12 × 40 × 80	1320–2000	CS: 2.4–36.6	WA: 8.1%–37.8% Apparent porosity: 18.5%–49.3%	Thermal conductivity: 0.155–0.742 W/mK Ignition loss: 7.8%–51.77% Efflorescence: Slight (<10% surface coverage) Optimum mix: 15% CarS +5% PMS fired at 1100°C	Yaras (2020)
PPR 60% (based on 1:1:3 ratio of cement:sand:paper pulp)	Mixing of wastepaper pulp, cement, and sand; molding; sun drying for 14d	230 × 110 × 80	1/3 to 2/5 lighter than conventional clay bricks	CS: 11.38 (at 28d)	WA: More than 20%	Lightweight - 1–2 kg per brick	Utilization of waste papers to produce ecofriendly bricks (2016)
Wastepaper 10%, 20%, 30% by weight	Mixing clay and paper waste, pressing into bricks, drying, and firing at 1000°C	85 × 85 × 10	1590 (10% waste), 1420 (20% waste), 1320 (30% waste)	CS: 12.6 (10%) 13.1 (20%) 7.0 (30%)	WA: 25.6% (10%), 32.8% (20%), 38.4% (30%) Porosity: 40.7% (10%), 46.7% (20%), 50.7% (30%)	Thermal conductivity: 0.50 W/mK (10%), 0.46 W/mK (20%), 0.39 W/mK (30%)	Sutcu et al. (2014)
PS: 10% (wet)	Mixing of clay and PS, extrusion, firing at 750°C in a modified dome type kiln	190 × 190 × 90	1590	CS: 2.6 ± 0.8	WA: 22.8% ± 0.7%	Linear shrinkage: 0.81% ± 0.03%	Vieira et al. (2016)

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TABLE 1 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Paper and Paperboard.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity	Other properties	Ref.
Lime sludge from paper industry: 10%, 20%, 30%, 40%, 50%	Mixing clay, sand and lime sludge in required proportions, molding into bricks, firing at 750°C in a modified dome type kiln	Indian standard size	lightweight compared to conventional clay bricks	CS: 3.1 (0%) 2.6 (10%)	WA: <20% for 0%, 10%, 20% sludge content (24 h immersion) Porosity increased with sludge addition	Soundness passed for bricks with up to 20% sludge Lower chloride content in bricks with up to 20% sludge, indicating lower corrosion tendency	Bhushan et al. (2021)
Wastepaper as main component	Soaking wastepaper in water, making paper pulp, mixing with cement and quarry dust/GGBS, molding into bricks, drying for 14d	230 × 110 × 80	1/3 to 2/5 lighter than conventional clay bricks	CS: 3.11 MPa after 14d	14.28% for 24 h immersion	Good thermal insulation (R-value of 2.0–3.0 per inch) Fire resistant - smokers like charcoal, does not burn with open flame	Kumari et al. (2019)
PPR 2.5%, 7.5%, 12.5%, 17.5%	Mixing clay and PPR, extrusion at 10 MPa, drying from 25°C to 105°C, firing at 900°C	45 × 45 × 160	Decreases from 1760 (control) to 1390 (17.5% PPR)	CS: Decreases from 11 MPa (control) to 3.2 (17.5% PPR) FS: 2–4	WA: Increases from 16% (control) to 25% (17.5% PPR) Apparent porosity: Increases from ~30% to ~47%	Thermal conductivity decreases from 0.53 to 0.412 W/m·K Linear shrinkage increases from 5.3% to 10.8%	Muñoz et al. (2020a)
PPR (KP) 5%, 10%, 15%, 20%	Mixing clay and KP, extrusion at 10 MPa, drying from 20°C to 105°C, firing at 900°C	45 × 45 × 160	Decreases from ~1840 (control) to 1380 (20% KP)	CS: Decreases from 11.5 (control) to 3.7 (20% KP) FS: 2.5–3.5	WA: Increases from 16% (control) to 25% (20% KP) Apparent porosity: Increases from 30% to 35%	Thermal conductivity decreases from 0.52 to 0.36 W/m·K Linear shrinkage increases from 4.55% to 7.29% Plasticity index increases with KP content	Muñoz et al. (2020b)
Deinking PS (DPS): 0%, 8%, 10%, 12%	Mixing clay and DPS, extrusion, drying at room temperature for 48 h then at 100°C for 24 h, firing at 850°C	85 × 55 × 45	Decreases from 1900 (0% DPS) to 1600 (12% DPS)	CS: Decreases from 8.78 (0% DPS) to 4.65 (12% DPS)	WA: Increases from 10.87% (0% DPS) to 16.58% (12% DPS) Porosity: Increases from 25% (0% DPS) to 35% (12% DPS)	Thermal conductivity decreases from 0.62 to 0.36 W/m·K Linear shrinkage increases from 6.9% to 8.55% Loss on ignition increases from 6.47% to 13.51%	Makni et al. (2024)
Micro cellulose fiber (CF): 2.5, 5, 7.5, 10, 15	Mixing clay and CF with 10%–12% water, molding into cylindrical samples under 20 MPa pressure, drying at 35°C for 24 h then 100°C for 24 h, firing at 950°C for 2h	Ø 22 x H11 (cylindrical)	Decreases from 2090 (0% CF) to 1510 (15% CF)	CS: Decreases from 25.4 (0% CF) to 1.4 (15% CF)	WA: Increases from 10.40% (0% CF) to 27.20% (15% CF) Apparent porosity: Increases from 20.09% (0% CF) to 40.94% (15% CF)	Thermal conductivity decreases from 0.893 to 0.267 W/m·K Loss on ignition increases from 4.73% to 17.79%	Arslan et al. (2021)

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TABLE 1 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Paper and Paperboard.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity	Other properties	Ref.
PPR 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20	Mixing clay, PPR and water, extrusion at 10 MPa, drying at room temperature for 24 h then at 105°C for 24 h	45 × 45 × 160	Decreases from 2000 (0% PPR) to 1500 (20% PPR)	CS: Increases from 3.4 (0% PPR) to 10.7 MPa (12.5% PPR), then decreases FS: Increases with PPR content	—	Thermal conductivity decreases from 0.861 to 0.603 W/m·K (30% reduction) Specific heat capacity decreases from 1.4 to 0.9 MJ/m3K	Muñoz et al. (2020c)
PS 5, 10, 15, 20	Mixing clay, sand and PS, molding, drying at 105°C, firing at 900°C and 1000°C for 1 h	60 × 30 × 18, 30 x 54, and 70 × 70 × 70 (different sizes used for different tests)	Decreases from 1800–2100 (0% PS) to 1310–1420 (20% PS)	CS: Decreases from 20–25 (0% PS) to 4–5 (20% PS)	WA: Increases from 8.2%–15.0% (0% PS) to 18.6%–26.3% (20% PS) Porosity: Increases from 21%–25% (0% PS) to 39%–46% (20% PS)	-	Kizinievič et al. (2018a)
Deinking PS (DPS) 8%, 10%, 12%	Mixing clays and DPS, extrusion, drying at room temperature for 48 h then at 100°C for 24 h, firing at 850°C	85 × 55 × 45	—	CS: Decreases from 8.78 (0% DPS) to 4.65 MPa (12% DPS)	WA: Increases from 10.87% (0% DPS) to 16.58% (12% DPS) Porosity: Increases from 25.31% (0% DPS) to 35.45% (12% DPS)	—	Makni et al. (2021)
Rejected contaminated fines (RCF) waste 5%, 10%, 15%	Mixing clay and RCF waste, compaction using IPC Global Servopac Gyratory Compactor, drying for 48 h at room temperature and 24 h at 105°C, firing at 950°C, 1000°C, and 1050°C	100 mm diameter, 50 mm height (for some tests)	—	CS: Decreases from 23.1 - (control) to 14.8 - (15% RCF)	WA: Increases with RCF content Apparent porosity: Increases from 23.52% (control) to 30.18% (15% RCF)	Thermal conductivity decreases with RCF content (up to 31.25% reduction) Initial Rate of Absorption (IRA) increases Durability: 10% RCF bricks classified as GP grade, others as PRO grade Leachable heavy metals within acceptable limits	Xin et al. (2023)
Sludge paper wastewater (SPW) 1%–10% Paper waste (PW): 1%–10%	Mixing clay and waste, compression molding at 54.5 MPa, drying for 48 h at 110°C, firing at 950°C for 6 h	60 × 30 × 10	Decreases with increasing waste content For 6% PW: Lowest BD is achieved	CS: Decreases with increasing waste content For 10% SPW: ~15 MPa For 10% PW: ~10 MPa	WA: Increases with waste content For 10% SPW: ~17% For 10% PW: ~23% Porosity: Increases with waste content	Thermal conductivity decreases with waste content For 6% PW: 0.115 W/m·K For 9% SPW: 0.182 W/m·K Linear shrinkage increases slightly (max 2% for SPW, max 1% for PW) Lower heating value: 1590.48 cal/g for SPW, 3683.7 cal/g for PW	Martínez et al. (2012)

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TABLE 1 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Paper and Paperboard.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity	Other properties	Ref.
Sugarcane pulp sand (SCPS) 10%, 20%, 30%, 40% Paper grain sand (PGS) 10%, 20%, 30%, 40% SCPS + PGS 10%, 20%, 30%, 40%	Mixing materials, compression molding, drying for 48 h at 110°C, curing in water for 28d	250 × 120 × 60	For 40% SCPS: 1910 For 40% PGS: 1800 For 40% SCPS + PGS: 1850	CS Control: 26.53 10% SCPS + PGS: 28.79 40% PGS: 21.13 FS: Control: 3.31 10% SCPS + PGS: 3.92 40% PGS: 2.55	WA For 40% SCPS: 5.4% For 40% PGS: 6.3% For 40% SCPS + PGS: 5.8% Apparent porosity For 40% SCPS: 21.4% For 40% PGS: 24.18% For 40% SCPS + PGS: 23.88%	Time to failure increases with increasing waste content	Tayeh et al. (2023)
Recycled paper mill waste (RPMW): 80%, 85%, 90%, 95% ()	Mixing RPMW and cement, compression molding at high pressure in two stages, sun drying between stages	230 × 105 × 80	Specific weight: 650–790 kg/m^3	CS: 9.0–9.9 All mixes experiences (about 3x higher than conventional clay bricks)	WA: 83%–108% Porosity: 13%–31%	Thermal stability up to 280°C Dimension change on drying: 6%–18% Dimension change on water absorption: 7%–30% Fibrous nature provides high energy absorption capacity Lightweight compared to conventional bricks	Raut et al. (2012)
Wastepaper aggregate (WPA): 62.5% Waste additive (binder): 12.5% Total waste content: 75%	Mixing components, molding using hydraulic press, and curing at room temperature for 28d	50 × 50 × 50 mm (test specimens)	901.5	CS: 2.71	—	Ultrasonic pulse velocity (UPV): 989.9 m/s Elastic modulus: 883.4 MPa	Oriyomi et al. (2025)
5% and 10% waste paper ash (WPA) as partial replacement for cement	Mixing cement, sand, WPA, and water; molding; curing for 14 days	150 × 110 × 70	1682 to 1872	—	WA: 3.49%–27.04%	—	Ekong et al. (2022)

strength as the percentage of TW increased. At 10% TW, the flexural strength decreased from 3.62 MPa (for the control bricks) to 2.12 MPa (Hussien et al., 2024). This reduction is consistent with the observed decrease in compressive and tensile strength, as the TW particles likely introduce voids and disrupt the overall bond strength of the material, making it more prone to bending and failure under load. In a similar study, bricks made with SCG showed a decrease in flexural strength from 4.20 MPa (at 0% SCG) to 2.95 MPa (at 10% SCG), which is again consistent with the negative impact of organic waste on the flexural properties of the material (Chung et al., 2021). The presence of SCG in the brick mix likely reduces the overall cohesion between the particles, which weakens the material's resistance to bending. On the other hand, some inorganic wastes can have a strengthening effect. For instance, bricks containing EP demonstrated improved flexural strength. Adding 5% EP to waste glass-based bricks increased the flexural strength from 3.40 MPa to 3.90 MPa (Tangboriboon, 2019). This improvement can be attributed to the reinforcing nature of eggshell powder, which enhances the material's structural integrity and helps resist bending forces. On the other hand, the mixture of different types of plastic waste (HDPE, LDPE, and PET) showed approximately double the value of conventional clay bricks, i.e., 8 MPa.

Generally, flexural strength in MSW-incorporated masonry units (Tables 1–5) generally benefits from low to moderate waste

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TABLE 2 Physico-mechanical properties of masonry units incorporating MSW materials namely: Food Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity (%)	Other properties	Ref.
TW 0, 2.5, 5, 7.5, 10	Unfired clay bricks, dried at room temperature (20°C) for 7d, then oven-dried at 60°C for 48h	50 × 50 × 200	0%: 1963.91 2.5%: 1844.07 5%: 1811.21 7.5%: 1627.41 10%: 1602.18	CS: 0%: 3.59, 2.5%: 4.17, 5%: 4.40, 7.5%: 2.87, 10%: 1.98 FS: 0%: 0.93, 2.5%: 1.19, 5%: 1.49, 7.5%: 0.99, 10%: 0.52	WA: 0%: 0.37, 2.5%: 0.82, 5%: 0.35, 7.5%: 0.37, 10%: 0.26 Porosity: Increases with TW content	Linear Shrinkage (%): Ranges from 4.29% to 5.46% Thermal Conductivity (W/mK): Increases with TW content (7.9, 8.5, 8.9, and 9.6 for 2.5%, 5%, 7.5%, and 10% TW respectively)	Hussien et al. (2024)
Spent coffee grounds (SCG) or TW 0, 1, 2.5, 5, 10, 15	Alkali-activated unfired bricks. Clay precursor mixed with NaOH and Na_2SiO_3 solution, additives added, molded under 2 MPa pressure, oven-dried at 110°C for 24 h, then cured at room temperature	115 × 110 × 76	Decreased as additive content increased	CS: 0%: 20.61 1%SCG: 18.39 1%TW: 21.23 2.5%SCG: 14.56 2.5%TW: 17.34 5%SCG: 3.87 5%TW: 9.81 10%SCG: 3.52 10%TW: 8.79 15%SCG: 2.74 15%TW: 4.53	Increased as additive content increased At 5% additive content, absorption increased by over 165% compared to control Porosity increased with additive content	Linear shrinkage decreased with additive content	Chung et al. (2021)
Eggshell powder 0, 1, 3, 5	Waste glass powder mixed with eggshell powder and sodium silicate, compression molded, dried at 110°C for 24 h, then fired at 800°C or 900°C	—	501–1600	CS 0% eggshell: 15.57 (800°C), 19.07 (900°C) 1% eggshell: 3.23 (800°C) 2.52 (900°C) 3% eggshell: 2.71 (800°C) 1.95 (900°C) 5% eggshell: 2.55 (800°C) 1.58 (900°C)	WA 0% eggshell: 2.84% (800°C), 1.01% (900°C) 1% eggshell: 10.31% (800°C), 20.04% (900°C) 3% eggshell: 21.49% (800°C), 29.63% (900°C) 5% eggshell: 24.43% (800°C), 45.25% (900°C)	Thermal expansion coefficient: 5.94–5.96 x 10^{-6}/°C (1% eggshell), 6.04 x 10^{-6}/°C (0% eggshell)	Tangboriboon (2019)
TW 0, 2.5, 5, 7.5, 10, 12.5	Clay and TW mixed with 15% water, pressed at 10 MPa, dried, fired at 950°C or 1050°C	12 × 40 × 80	0% TW: 1790 (950°C), 1880 (1050°C) 2.5% TW: 1770 (950°C), 1820 (1050°C) 5% TW: 1670 (950°C), 1680 (1050°C) 7.5% TW: 1560 (950°C), 1600 (1050°C) 10% TW: 1480 (950°C), 1490 (1050°C) 12.5% TW: 1380 (950°C), 1410 (1050°C)	CS 0% TW: 32.2 (950°C), 34.2 (1050°C) 2.5% TW: 28.4 (950°C), 31.3 (1050°C) 5% TW: 19.8 (950°C), 22.0 (1050°C) 7.5% TW: 14.5 (950°C), 15.3 (1050°C) 10% TW: 9.3 (950°C), 10.5 (1050°C) 12.5% TW: 6.6 (950°C), 6.9 (1050°C)	WA 0% TW: 17.8 (950°C), 15.9 (1050°C) 2.5% TW: 20.3 (950°C), 18.5 (1050°C) 5% TW: 24.6 (950°C), 23.5 (1050°C) 7.5% TW: 28.9 (950°C), 27.1 (1050°C) 10% TW: 32.1 (950°C), 30.8 (1050°C) 12.5% TW: 35.3 (950°C), 33.9 (1050°C) Porosity (%) 0% TW: 32.0 (950°C), 30.1 (1050°C) 2.5% TW: 36.0 (950°C), 33.8 (1050°C) 5% TW: 41.1 (950°C), 39.5 (1050°C) 7.5% TW: 45.2 (950°C), 43.4 (1050°C) 10% TW: 47.6 (950°C), 46.0 (1050°C) 12.5% TW: 48.8 (950°C), 47.9 (1050°C)	Thermal conductivity: 0.410–0.764 W/mK Microporous structure with pores <100 µm Main crystalline phases: quartz, hematite, orthoclase	Ozturk et al. (2019)

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TABLE 2 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Food Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity (%)	Other properties	Ref.
Wine lees (WL), grape seeds (GS), or mixture (MIX) 0, 5, 10	Clay mixed with wine waste, extruded, dried at room temperature for 24 h and then at 100°C for 2 h, fired at 980°C, 1000°C or 1020°C	140 × 24 × 11	0%: 1650–1680 5% WL: 1440–1480 5% GS: 1300–1380 5% MIX: 1290–1390 10% WL: 1320–1460 10% GS: 1170–1200 10% MIX: 1240–1260	FS 0%: 13.2–14.5 5% WL: 10.8–12.0 5% GS: 7.2–8.5 5% MIX: 6.8–8.0 10% WL: 8.2–9.5 10% GS: 4.8–5.5 10% MIX: 5.2–6.0	WA (%) 0%: 15–16 5% WL: 23–24 5% GS: 27–29 5% MIX: 30–31 10% WL: 31–35 10% GS: 39–41 10% MIX: 36–37 Porosity 0%: 5% 5% WL: 9%–10% 5% GS: 17%–18% 5% MIX: 17%–18%	Thermal conductivity (W/mK) 0%: 0.70 5% WL: 0.57 5% GS: 0.35 5% MIX: 0.45 Linear shrinkage: 6.0%–8.1% Loss on ignition: 14.0%–21.5%	Taurino et al. (2019)
CP biosolid 0, 4, 8, 12, 16	Clay mixed with CP, 10 MPa compaction, dried, fired at 800°C and 1000°C for 60 min	40 × 35 × 120	0% CP: 2050 (1000°C) 16% CP: 1460 (1000°C)	CS 0% CP: 19.25 (1000°C) 16% CP: 5.47 (1000°C)	WA (%) 0% CP: 8.87 16% CP: 18.69 Porosity: Increased with CP content, up to 48.8% for 16% CP	Linear shrinkage: 3.07%–9.24% Thermal conductivity (W/mK) 0% CP: 0.78 (1000°C) 16% CP: 0.57 (1000°C)	Adazabra et al. (2024)
Sago fine waste (SFW) 0, 2, 4, 6, 8, 10	Cement mixed with SFW, molded, cured for 7 and 28d	215 × 102.5 × 65	0% SFW: 2103–2127 10% SFW: 1687–1796	CS 0% SFW: 25.31–27.21 10% SFW: 7.09–8.32	WA (%) 0% SFW: 11.93–12.4 10% SFW: 15.4–16.3	Two water-cement ratios tested: 0.5 and 0.6	Norhayati et al. (2023)
TW 0, 2, 4, 6, 8, 10, 12	Zeolite tuff mixed with TW, dry pressed at 40 MPa, sintered at 950°C–1250°C for 3h	25 mm diameter, 10 mm thick disks	0% TW: 1670–1850 12% TW: 1370–1410	CS 0% TW: 25–36 12% TW: 5.5–7.5	WA (%) 0% TW: 9–15 12% TW: 25–28 Apparent porosity (%): 0% TW: 28–30 12% TW: 37–39	Thermal conductivity (W/m·K): 0% TW: 0.55–0.70 12% TW: 0.17–0.24	Ibrahim et al. (2023)
Spent mushroom material (SMM): 0, 5, 7.5, 10, 12.5, 15	Mixing clay and SMM, molding under 10 MPa pressure, drying at 120°C, firing at 700°C, 800°C, and 900°C for 4h	50 × 50 × 50	Decreases from 1922 (0% SMM) to 1420 (15% SMM) at 900°C	CS 0% SMM: 18.4 15% SMM: to 8.7 (900°C)	WA (cold): 13.9% (0% SMM) to 23.6% (15% SMM) at 900°C WA (boiling): Increases from 17.2% (0% SMM) to 25.3% (15% SMM) at 900°C Apparent porosity: Increases from ~24% to ~36% at 900°C	Thermal conductivity decreases from 0.77 to 0.29 W/mK at 900°C Linear drying shrinkage increases from 3.17% to 4.9% Linear firing shrinkage increases from 1.7% to 7.6% at 900°C Lightweight compared to conventional clay bricks	Ali et al. (2023)

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10.3389/fbuil.2025.1621305

10.3389/fbuil.2025.1621305

TABLE 2 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Food Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity (%)	Other properties	Ref.
Peanut kernel (PA): 6, 20.5, 35 Peanut grain (PB): 6, 20.5, 35	Mixing clay and PA or PB, molding under 4 MPa pressure, drying at 50°C for 24 h, 80°C for 3 h, and 110°C for 3 h, firing at 725°C, 800°C, and 875°C for 2 h	50 × 50 × 50	Decreases with increasing peanut waste	CS For PA, decreases from 109.85 (6% at 725°C) to 5.10 (35% at 875°C) For PB, decreases from 126.33 (6% at 725°C) to 6.31 (35% at 875°C)	WA Increases with waste Apparent porosity: Increases with peanut waste	Linear drying shrinkage increases from 3.17% to 4.9% as peanut waste increases Linear firing shrinkage increases with peanut waste and firing temperature Optimum conditions: 6% peanut at 725°C firing temperature	El-Mekkawi et al. (2022)
Peanut shells powder (PSP) 0, 10, 15, 20, 25, 30, 40	Mixing clay and PSP, compressing under 10 MPa pressure, drying at room temperature (30°C ± 7°C, 45% ± 5% humidity) for 21d	160 x 50 (cylindrical) or 40 × 40 × 160 (prismatic)	Decreases from 2010 (0% PSP) to 1240 (40% PSP)	CS: Increases from 4.21 (0% PSP) to 5.19 (20% PSP), then decreases to 2.35 (40% PSP)	WA: Increases from 15.5 to 38.3 g/cm^2.min 0.5 as PSP content increases Porosity: Increases from 25.40% (0% PSP) to 54.07% (40% PSP)	Thermal conductivity decreases from 1.44 to 0.76 W/m.K as PSP content increases from 0% to 40% Resistance to rain erosion improved with 15%–30% PSP content Ductility increases with increasing PSP content Ultimate strain increases from 0.92 mm to 8.49 mm as PSP content increases from 0% to 40% Optimum PSP content for mechanical properties is 15%–25% All samples except 40% PSP meet load-bearing wall strength requirements (>4 MPa)	Sory et al. (2022)
Cashew nut shell powder (CNSP) 10, 20, 30, 50, 60 Groundnut shell powder (GSP) 5, 10, 15 Groundnut shell ash (GSA) 2, 4, 5, 6, 8, 10 Hazelnut shell powder (HSP) 2.5, 5, 7.5, 10	Mixing CNSP, GSP, GSA, HSP with clay, molding, drying, and firing at 950°C–1100°C	CNSP: 225 × 100 × 75 GSP: 70 × 40 × 18 GSA: 1850 × 850 × 650 HSP: 200 x 85.6(diameter)	GSA:1225–1426 HSP: 1410–1700	CS CNSP: 1.2–3.5 GSA: 7–17 HSP: 30–32 FS GSA: 0.11 GSP: 5.49–9.1	WA CNSP: 18%–43% GSA: 15.33%–25% HSP: 21.25%–36.1% Porosity GSP: 25.15%–28.04% HSP: 36.25%–51.35%	Thermal conductivity decreases with increasing nut shell content Higher firing temperatures generally increase strength and decrease porosity Most samples meet minimum strength requirements for load-bearing applications	Jannat et al. (2021)

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TABLE 2 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Food Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	CS and FS (MPa)	WA and porosity (%)	Other properties	Ref.
Groundnut shell ash (GSA) 0, 10, 20, 30 40	Mixing soil, cement, GSA, and water, compressing into blocks, curing for 28d	50 × 50 × 50 (cubes) 40 × 40 × 160 (beams) 100 × 100 × 60 (blocks)	Decreases from 2124 (0% GSA) to 1961 (40% GSA)	CS Decreases from 13.18 (0% GSA) to 7.41 MPa (40% GSA) at 28d FS Decreases from 5.91 (0% GSA) to 3.42 (40% GSA) at 28d	WA Increases from 12.22% (0% GSA) to 15.19% (40% GSA)	Thermal conductivity decreases with increasing GSA content Resistance to acid and alkaline attack improved up to 20% GSA replacement Optimum GSA replacement level found to be 10%–20%, considering strength and durability Even 40% GSA replacement meets minimum strength requirements for load-bearing applications	Sathiparan et al. (2023)
Cashew apple ash (CAA) 0, 5, 10, 15, 20, 2	Mixing sand, cement, CAA, and water (ratio 1:6, w/c 0.5), compressing into blocks using machine, curing by sprinkling for 7-28d	130 × 100 × 100	Decreases from 2268 (0% CAA) to 2134 (25% CAA)	CS Decreases from 12.14 (0% CAA) to 5.93 (25% CAA)	WA Ranges from 2.66% (25% CAA) to 2.81% (5% CAA)	All mixes meet minimum standards for compressive and tensile strength Split Tensile Strength (STS): Decreases from 1.179 MPa (0% CAA) to 0.934 MPa (25% CAA) at 28d	Korankye and Danso (2024)
Eggshell ash (ESA) 0, 5, 10, 15, 20, 25, 30, 35, 40	Mixing sand, cement, ESA, (ratio 1:6, w/c 0.5), compacting into molds, curing 7-28d	50 × 50 × 50	—	CS Decreases from 5.1 (0% ESA) to 4.1 (40% ESA) at 28days. Optimal strength of 4.7 MPa at 30% ESA at 28d	—	30% ESA replacement provides optimal. ESA acts as an accelerator - higher early strength gain	O and Fop (2017)

10.3389/fbuil.2025.1621305

10.3389/fbuil.2025.1621305

TABLE 3 Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Recycled (PET) + (PU) binder 20, 40, 60, 80	PET waste shredded to 0.75 mm size with PU binder molded and compacted in interlocking brick machine mold	—	—	CS 1.8–5.3	-	Tensile strength: 0.4–1.3 MPa Impact strength: 19.5–23.3 J/m Thermal conductivity: 0.15–0.22 W/mK Suitable for non-load bearing walls and partitions	Alaloul et al. (2020)
0, 1, 3, 7 shredded plastic waste (polyethylene terephthalate bottles)	Soil mixed with plastic waste, compacted using hydraulic machine	—	—	CS Without plastic: 0.45 With 1% plastic: 1.55 Optimal at 1% plastic	—	Erosion rate increased with increasing plastic content Durability decreased with increasing plastic content Suitable for lightly-loaded	Akinwumi et al. (2019)
Glass waste (GW): Up to 55 (<0.4 mm particles) Plastic waste (PET): Up to 2 Combined: Up to 25 glass +2 plastic	Mixed with alkaline activator, compressed at 8 tons, cured at 50°C/90% RH (48 h), then 155°C (24 h)	115 × 110 × 76	—	CS Control (no waste): 40 55 wt% GW (<0.4 mm): 22 2 wt% plastic: ~32 25 wt% glass +2 wt% plastic: ~25	WA Control: ~15 55% glass: ~13 2% plastic: ~16 25% glass +2% plastic: ~14	Linear shrinkage decreased with waste content Good thermal stability No firing required Reduced energy consumption	Zhang et al. (2022)
5, 10, 15 polypropylene (PP) waste fibers	Mixed with cement, fly ash, M sand, molded, cured for 7-28d	230 × 110 × 90	-	CS Mix 1 : 13.44 at 28d Mix 2 : 16.85 at 28d Mix 3 : 12.62 at 28d	WA Mix 1: 10.17% Mix 2: 7.89% Mix 3: 6.58%	Passed hardness, soundness, efflorescence tests Lower weight than conventional bricks More cost-effective	Rauniyar et al. (2024)
LDPE (Low-Density Polyethylene) with bottom ash, ceramic, or copper slag (2:1, 3:1, 4:1)	Mixed, heated at 170°C (3 h), compressed at 35 MPa (5 min), cooled	70 × 70 × 140, cut into 30 × 30 × 30 mm cubes for testing	LDPE Ash: 850–92 LDPE Ceramic: 1140–1290 LDPE Slag: 1310–1540	LDPE:Bottom Ash (3:1) - 32.46 MPa LDPE:Ceramic (3:1) - 22.12 MPa LDPE:Copper Slag (2:1) - 21.43 MPa	WA LDPE:Bottom Ash - 1.5%–4.9% LDPE:Ceramic - 4.3%–6.9% LDPE:Copper Slag - 1.7%–2.3%	10% used engine oil improved properties Lower density and water absorption	Monish et al. (2021)
Scrap plastic waste (SPW): 20, 30, 40 + (foundry sand)	Foundry sand and melted plastic at 220°C, compressed at 5 MPa, cooled	222 × 106 × 73	Comparable to C20/C25 concrete (2240–2400)	CS: 29.45 (20%) to 38.14 (30%) TS: 7.36 to 9.51	Low absorption Porosity decreases with content	Higher acid resistance Good ductility (TS/CS: 0.18–0.28 Faster curing (12 h to reach 80% strength) Lower energy use in production	(Aneke and Shabangu, 2021)

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TABLE 3 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
100% recycled HDPE or PP	Shredded to 10–20 mm, heated to 230°C, molded, cooled 24 h	190 × 90 × 90	HDPE brick: 864 PP brick: 877	CS HDPE brick: 11.19 PP brick: 10.02	WA HDPE brick: 0.752% PP brick: 0.370%	No efflorescence 55% lighter than clay bricks HDPE wall had 28.6% higher load capacity Lower heat transfer	Kulkarni et al. (2022)
100% HDPE plastic waste	Cleaned, melted at 130°C (20–60 min), molded, cooled 2 days	240 × 120 × 60	—	CS Average: 24 Individual bricks: 23–25	—	Meets Ethiopian Standard Class A Dimensional tolerances within standards Low fire resistance Lightweight compared to clay bricks	Belay Wendimu et al. (2021)
0.5–100 plastic waste	Mixed with other materials, molded, compressed	—	551–2410 depending on mix	—	WA 0–64.15, decreased with plastic Porosity increased (up to 40.2)	Thermal Conductivity: 0.00171 W/mK TS: 0.42–9.60 Lower density Lower production temperatures (220 °C vs. 1100 °C)	Singh et al. (2023)
16.67–25 LDPE	Melted with sand, molded, pressed	—	—	CS: (25%): 9.72 (20%): 12.28 (16.67%): 3.39	—	Tensile strength: 654–805 Thermal resistance: 110°C–181°C Zero efflorescence Scratch resistant	Sahani et al. (2022)
PET and HDPE: 10, 25, 40 Waste sand: 90, 75, 60	Mixed, heated to 700°C (15 min), poured, cooled	230 × 115 × 75 55 × 10 × 10	—	CS 133 (optimal at 25% plastic)	—	Optimal mix 72.59% stronger than conventional Statistical analysis used for optimization Simple production	Bhat et al. (2020)
Mixed, heated to 700°C (15 min), poured, cooled	Mixed with clay, molded, fired at 1100°C (23days)	228.6 × 114.3 × 76.2	Control: ~1600 15%: ~1260	CS Control: ~36 15% plastic: ~16	WA 0%–7.5%: <15 10%–15%: 15–20	Shrinkage decreases up to 10% plastic Lightweight, earthquake-resistan 7.5% optimal content	Idrees et al. (2023)
Plastic + Sand: 50:50	Plastic melted at 249°C, mixed with sand, poured, cooled	228.6 × 114.3 × 76.2	~1600 (21.8% lower than clay bricks)	CS: 8.23 FS: ~8 (twice that of clay bricks)	WA ~1.5 (lower than clay)	1.35x higher tensile strength No efflorescence Better thermal insulator (0.66–0.69 W/mK) Ductile failure mode	Subhani et al. (2024)
LDPE 20–33 M-sand: 67–80	Heated to 180°C, mixed, poured, cooled	190 × 90 × 90	—	CS: (25% LDPE): 3.77 20% LDPE): 12.23 (16.7% LDPE): 3.63	WA 1:3 mix: 0.34% 1:4 mix: 0.59% 1:5 mix: 0.64%	1:4 mix 2.3x tougher than clay bricks Negligible efflorescence Stable up to 180°C Better hardness	Arun Solomon et al. (2023)

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10.3389/fbuil.2025.1621305

TABLE 3 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
HDPE 25–50 Portland cement: 50–75	Mixed, molded, cured for 7-28d	cube samples	0% HDPE: 2000 50% HDPE: 1360	CS 0% HDPE: 24 35% HDPE: 13.8 50% HDPE: 9.2	WA 0% HDPE: 0.18 50% HDPE: 0.83	Suitable up to 35% HDPE Higher content reduces density Stable up to 35°C–40°C (12 h)	Sarwar et al. (2023)
Recycled plastic waste (RPW) used to fully replace cement in some samples	Molten plastic used as binder, mixed with sand and quarry dust	200 × 100 × 100	Less in plastic (LP): 2140.75 High in plastic (HP): 2286.50	CS LP: 7.31 N/mm2 at 21 days HP: 8.53 N/mm2 at 21 days	WA LP: 2.7% after 72 h HP: 0.5% after 72 h Porosity LP: 19.22% HP: 13.72%	Hydrophobic Over 80% final strength within a day Less prone to chemical attack Suitable for waterlogged areas	Agyeman et al. (2019)
20–40 RPW as cement replacement	Shredded to 4–5 mm, heated to 110°C, mixed with sand, poured, coole	50 × 50 × 50	—	CS 30% optimal: 22.7 (12% higher than cement-based) Decreased 10%–20% at (50°C–60°C)	WA 1.02–2.7 for plastic blocks vs. 9.32 for cement-based	52% lower cost at optimal 30% No curing time required	Asif and Javed (2024)
20–40 LDPE as cement replacement	Shredded, mixed with sand, heated to 200°C for 25–30 min, poured, cooled 24 h	50 × 50 × 50	—	CS Optimal mix (30% plastic): 18.06 With 0.5% basalt fibers: 22.82	—	No curing time required (usable after 24 h) Optimal sand particle size <0.42 mm 0.5% basalt fibers increased CS by 26.34%	Iftikhar et al. (2024)
25 plastic waste (polyethylene from water sachets and bottle caps) + 75 sand	Mixed, extruder at 250°C–300°C, compressed, water-cooled for 10 min	356 × 152 × 127	(1500–1600)	CS Bottle cap: 15.0 Water sachet: 13.3 Mixed plastic: 14.8	—	Higher strength-to-density ratio than sandcret No curing time required High water and chemical resistance	Kumi-Larbi Jnr et al. (2023)
40–70 RPW (PP/PS, HDPE, mixed plastics)	Mixed with sand, heated to 200°C–300°C, poured, cooled	60 × 60 × 60 hexagonal units	1138–1570	CS PP/PS: 10.25–15.85	WA 0.19–1.30	Setting time: 19–25 min (initial/final) Abrasion resistance: 0.38%–2.68% wear No curing required Uses 1.8 kg plastic waste per block	Tempa et al. (2022)
LDPE + Bottom ash + Copper slag + Crushed ceramic	Mixed by hand, heated at 170°C for 3 h, compacted under 35 MPa for 5 min, cooled 24 h	7 × 7 × 14 blocks cut into 3 cm cubes	850–1540	CS 10–32 Ash 3:1 with 10% oil	WA 1.5–7.8 Ash 3:1 with 10% oil	Addition of used engine oil as coupling agent improved properties PET did not fully melt at 170°C Fire resistance needs further research	Monish et al. (2021)

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TABLE 3 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Plastic waste (PET): 20, 25, 33.33	Crushed plastic (2–3 mm) mixed with heated M-sand (270°C), cooled 2–3 h	Brick pavers	Brick: 1089–1172	CS Brick: 39.33–41	—	Ultrasonic pulse velocity: 4.45–4.7 m/s Suitable for road paving Concerns about microplastic release	Agrawal et al. (2023)
PVC or PS: 5–2	Mixed with cement, aggregates, molded, vibrated, cured at 95% RH and 23°C for 24 h	101.6 × 203.2 × 406.4	PVC: 2214.5–2261.2 PS: 2214.5–2268.3	CS PVC: 4.14–4.67 PS: 4.14–4.73	Apparent Porosity PVC: 22.11–22.53 PS: 21.76–22.53	Workability increases with plastic content PS has higher workability than PVC PS blocks have slightly higher strength Suitable for massive concrete structures	Hhm (2025)
Waste plastic (PVC or PS): 20–40	Mixed, heated to 250°C, molded, cooled	—	20%: 1723 30%: 1567 40%: 1337	CS 20%: 37.42 30%: 34.70 40%: 23.90	—	Impact strength: Plastic blocks withstood 10 impacts (34.9 J) vs. 1 impact (6.98 J) for conventional Lower self-weight	Kadam et al. (2024)
PET: 0–25	Mixed with cement and aggregates, cured in water for 7-28d	100 × 100 × 100	0%: ~2400 5%: ~2390 15%: ~2250 25%: ~2040	CS 0%: ~40 5%: ~18 15%: ~10 25%: ~2.4	—	Slump increased with PET content (70 mm for 0% to 170 mm for 25%) Thermal conductivity decreased with PET content Suitable for insulating applications	Halim et al. (2019)
Plastic bottles (350 mL volume): 23 voids created in blocks	Mixed with crushed clay bricks, cement, sand, plastic bottles, cured	400 × 200 × 150	Without bottles: 2004.83 With bottles: 1595.60–1599.10	CS Without bottles: 18.05 at 28d With bottles: 12.46–12.89 at 28d	WA Without bottles: 170.7 With bottles: 134.9	Thermal conductivity reduced by >50% with bottles (0.314–0.308 W/m.K vs. 0.675 W/m.K) Lower ultrasonic pulse velocity, better sound insulation Suitable for thermal insulation	Kougnigan et al. (2023)
PET: 30	Shredded, melted, mixed with sand, cement, water, molded into paving blocks	—	—	CS Average: 35 Variation: ±5	WA Similar to conventional paving blocks	Lower carbon footprint More cost-effective Comparable durability Meets required standards	Rahmi et al. (2025)
Plastic bottles (350 mL): 23% voids	Self-compacting concrete mixed, bottles placed, poured without vibration	400 × 150 × 200	Without bottles: 2283.2 With bottles: 1633.3–1675	CS Without bottles: 20.2 With bottles: 9–13	WA Without bottles: 120.1 With bottles: 66.4–66.7	Thermal conductivity reduced by 53%–56% Better sound insulation Meets ASTM C129 requirements Lightweight compared to conventional	Robleh et al. (2021)

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10.3389/fbuil.2025.1621305

TABLE 3 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Wood waste (pine sawdust or sengon flakes): 50 Palm fiber (ijuk): 15–30 Plastic waste (PP or PE): 15–35	Mixed, hot pressed at 180°C and 25 kg/cm^2 for 20 min	300 × 300 × 15	699–874	FS (MOR): Highest: 194.11 (PE matrix, sengon wood, 50:30:15 ratio)	WA 34.68%–97.32%	Moisture content: 1.47%–5.01% MOE: Highest 20,450.67 kg/cm^2 Internal bond strength: 1.63–2.95 kg/cm^2 Screw withdrawal strength: Highest 71.33 kg	Abdurachman (2021)
Plastic waste (PET): 0–15	Mixed with cement, sand, coarse aggregate/plastic, cast, cured for 7-28d	100 × 100 × 100	0% plastic: 2730–2980 5% plastic: 2340–2600 10% plastic: 2530–2700 15% plastic: 2267–2600	CS 0% plastic: 16.9 5% plastic: 17.2 10% plastic: 16.8 15% plastic: 14.9	WA) 0% plastic: 4.1% 5% plastic: 3.5% 10% plastic: 2.5% 15% plastic: 1.8%	Slump decreased from 65 mm (0% plastic) to 5 mm (5%–15% plastic) Aggregate impact value of plastic: 49.95% Optimal replacement: 10% plastic Suitable for low-load bearing applications	Olamoju et al. (2023)
PET or LDPE: 0–50)	Mixed per ACI design method, cast into molds, cured for 7-28d	Cubes: 100 × 100 × 100 Cylinders: 100 dia x 200 Prisms: 100 × 100 × 500	—	CS 10% PET: 33.48 10% LDPE: 32.17	WA: 10% PET: 4.48% 10% LDPE: 9.70%	Split tensile and flexural strengths decreased Water absorption increased PET performed slightly better than LDPE	(Ejiogu, 2025)
Various percentages of plastic waste (PET, LDPE)	Mixed with cement and aggregates, molded, cured	Varies by study	Generally decreases with increasing plastic	Generally decreases with increasing plastic	Decreases with increasing plastic	Lower thermal conductivity More ductile failure mode Suitable for non-load bearing applications Lighter weight	Uvarajan et al. (2022)
Plastic waste (PET and HDPE): 20–95 Pit sand or sea sand: 80–5	Shredded, mixed with sand, heated to 175°C, poured, cooled	50 × 50 × 50	—	CS Plastic-pit sand pavement block (PPPB): Max 36.96 Plastic-sea sand pavement block (PSPB): Max 27.81	WA PPPB: Max 3.98% (at 20% plastic) PSPB: Max 4.60% (at 20% plastic)	Water absorption decreases with plastic content Strength increases with plastic, plateaus at 80%–90% Tensile Strength: PPPB: Max 8.2 PSPB: Max 6.1	Tulashie et al. (2020)
Expanded polystyrene (EPS): 10–26	Mixed with cement mortar, molded into hollow blocks with two cylindrical holes, cured for 28d	400 × 200 × 200 with two 125 mm diameter holes	Control (0% EPS): 2092–2157 10% EPS: 1750–1910 15% EPS: 1408–1497 20% EPS: 1242–1265 26% EPS: 956–982	CS (Net area) Control: 9.5 10% EPS: 6.3–6.9 15% EPS: 4.1–4.9 20% EPS: 4.0–4.5 26% EPS: 2.4	WA Control: 0.47%–0.93% EPS blocks: 2.76%–4.61%	Block weight decreases from 23.5 kg to 10.6 kg (26% EPS) Failure becomes more gradual with EPS Skin reinforcement improves failure pattern Acid/salt resistance improves with EPS	Ali et al. (2020)

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TABLE 3 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials, namely: Plastic Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strength (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Crushed glass: 0–20 HDPE granules: 0–20	Mixed with cement, gravel, superplasticizer and water, cast, cured in water for 28d	50 × 50 × 50	Control: 1880 20% crushed glass: 1960 20% HDPE: 1770	CS Control: 21.51 20% crushed glass: 27.00 20% HDPE: 3.60	WA Control: 4.16% 20% crushed glass: 2.33% 20% HDPE: 5.95%	Glass increased strength, decreased absorption HDPE decreased strength, increased absorption All mixes met Thai standards for non-load bearing More voids/cracks with waste content	Kuekham et al. (2024)
PET with ferrous metal shavings L-1: 85.7 PET, 14.3 ferrous L-2: 93.7 PET, 6.3 ferrous L-3: 87.4 PET, 12.6 ferrous L-4: 92.1 PET, 7.9 ferrous L-5: 92.3 PET, 7.7 ferrous	Handmade by melting PET and metal in artisan LPG furnace, cast in wooden molds, air dried	239–241 x 129–131 x 67–87	—	CS L-1: 19.4, L-2: 11.0, L-3: 12.7, L-4: 12.1, L-5: 16.6	—	Warpage: 2–3 mm	Suasnabar et al. (2023)
85 ferrosilicon slag, 15 alumina waste	Materials dried, crushed to <0.15 mm, mixed with alkaline solution, pressed at 20 MPa, cured at room temperature for 28d	50 × 50 × 50	1599	10.9	WA 15.7% (cold), 18.7% (boiling) Porosity: 32%	Thermal conductivity: 0.33 W/m*K	Ahmed et al. (2021)

TABLE 4 Physico-mechanical properties of masonry units incorporating MSW materials namely: Glass Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strengths (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Glass waste (GW): 10%–40% Drinking water treatment sludge (DWTS): 40%–60%	Dry mixing of clay + sand with DWTS and GW Watering Keeping at 95% humidity for 3days at laboratory conditions Further drying in oven (60°C and 105°C) Burning at 900°C and 1000°C for 36 h	50 × 50 × 50	1035–1470	CS: 6–14.4	WA: 18.5%–43.4% Effective porosity: 27.2%–57.2% Total open porosity: 36.8%–68.0%	Thermal conductivity: 0.23–0.26 W/(m·K) Linear shrinkage: 8.0%–10.1% Color changes to darker red due to high Fe_2O_3 content from DWTS	Kizinievič et al. (2018b)
Electroplating sludge: 10 wt% GW powder: 5–30 wt%	Raw materials dried at 105°C for 24 h and passed through 74 μm sieve Ball milled for 300 min for homogenization Shaped under 40 MPa pressure Fired at 950°C for 3 h	50 × 35 × 10	—	CS: 20–32.7	WA Decreased from 7.64% to 2.74% Open porosity: Decreased from 10.69% to 1.16% BET surface area: Decreased from 0.84 to 0.05 m2/g	Matrix became more dense with waste glass addition Improved immobilization of heavy metals Met regulatory standards when waste glass content >20 wt%	Mao et al. (2018)
GW: 78% PET-G recycled content: 8%	3D printing of PET-G at 240°C nozzle temperature Mixing cement-glass mortar with water, glass powder, glass aggregate Compacting mortar with printed scaffolds in molds using vibration table, Curing at 21°C and 50% humidity	150 × 150 × 150 (thermal test samples) 40 × 40 × 160 (bending test samples), and 40 × 40 × 40 (compression test samples)	Decreases from 2157 (control) to 1982 (with PET-G scaffolding)	CS: 43–45 FS: 6.23–8.12	—	Thermal conductivity: 0.87 W/mK Thermal diffusivity: 0.64 μm2/s Specific heat: 1.36 MJ/m3K	Małek et al. (2024)
2–5 wt% funnel glass (cathode tube) or panel glass (screen)	Clay grinding Hand mixing, glass, and water Plastic extrusion Drying at ambient temperature for 48 h then at 100°C overnight Firing at 900°C–1000°C for 4 h	100 × 20 × 10	1650–1730 (clay brick body), and 2000–2009 (roof tile body)	FS: 16–22 Dry bending strength: 4.3–9.1	WA: 17%–19% (clay brick body), 5%–9% (roof tile body) Open porosity: 29%–32% (clay brick body), 11%–18% (roof tile body)	Reduced plasticity during shaping/drying Enhanced sintering during firing Low leaching of heavy metals Limited volatilization during firing	Dondi et al. (2009)
0%–45% GW	Mixing with clay and water Drying at controlled temperature Firing at 650°C–1100°C for 1–36 h	50 × 50 × 50, and 40 × 40 × 40	—	CS: 8.5–87	WA decreases with increasing glass content porosity decreases with higher glass content and firing temperature	Shrinkage: 0%–9% Lower sintering temperatures with glass addition (reduced to ~650°C) Improved thermal properties	Khokhar et al. (2023)

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TABLE 4 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Glass Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strengths (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
GW: Up to 55 wt% (<0.4 mm particle size) Plastic waste (PET): Up to 2 wt% Combined: Up to 25 wt% glass +2 wt% plastic	Materials dried at 105°C for 24 h Mixed with alkaline activator (20 wt% of dry mix) Compression molded at 8 tons pressure Cured at 50°C/90% RH for 48 h then 155°C for 24 h	= Block: 115 × 110 × 76 Cylinder: Ø 19 H127	—	CS:Glass waste only: 22–40, Plastic waste only: 20–40, and Combined waste: 22–35	WA Glass waste: 5%–20% Plastic waste: 10%–20% Combined: 5%–20%	Linear shrinkage decreased with waste addition Thermal stability improved with glass addition Good interfacial bonding with glass particles Poor bonding with plastic particles	Zhang et al. (2022)
Glass Sludge (GS): 25% Marble Sludge (MS): 5% Rice Husk (RH): 5% Combinations: G20M5, G20RH5, M5RH5	Dry mixing of materials Wet mixing with 18%–25% water Sun-dried for 3 days Burnt in industrial kiln at ~800°C for 3 days	228 × 114 × 76	Decreased for all mixes except G25 Lowest weight: RH5 and M5RH5 (5%–7% lower than control)	CS: G25: ~29% higher than control M5, G20M5, G20RH5: Similar to control RH5: 11% lower than control M5RH5: 17% lower than control FS G25: ~2x higher than control M5, G20M5, G20RH5: Similar to control RH5: 9% lower than control M5RH5: 11% lower than control	WA: 4%GS lower than control, G20M5: Similar to control. G20RH5: 3% higher than control. RH5: 5% higher than control. M5RH5: 8% higher Porosity: 20 G% lower than control, G20M5: Similar to control. G20RH5: 4% higher than control. 5%RH higher than control. M5RH5: 7% higher than control	Shrinkage: Decreased with waste addition (Control: 5%, waste mixes: 3%–4%) Thermal Properties Control: 0.53 W/mK Improved thermal performance: G20M5 (0.52), M5 (0.51), G20RH5 (0.50), RH5 (0.48), M5RH5 (0.45) G25: Higher conductivity at 0.59 W/mK Durability Efflorescence: All samples below 10% Sulfate resistance: Better performance in G25, control, and G20M5	Munir et al. (2021)
Waste glass: 0%, 5%, and 10% by weight	Mixed in porcelain ball mill Added 20%–25% water Hand molded Air-dried at room temperature (25°C–30°C) for 24 h Oven dried at 110°C ± 5°C for 24 h Fired at 900°C–1000°C for 1 h (8 h heating time)	140 × 65 × 40	1700–1760	(CS): 19.30–24.65 MPa (with 5%–10% waste glass) 20.18 MPa (control at 1000°C)	WA: 14.78%–18.66% Porosity: 29.71%–35.17%	Firing shrinkage: 3.41%–4.34% (with waste glass) Increased glass phase and reduced porosity Enhanced densification Met ASTM C62 standards Lower firing temperature possible (900°C vs. 1000°C) with 10% waste glass	Phonphuak et al. (2016)
Waste Glass Sludge (WGS): 5%, 10%, 15%, 20%, and 25% by weight of clay	adding 22.6%–18.9% water and resting for 3 h. The mixture was then molded, sun-dried for 2 days, and fired in a kiln at 850°C for 36 h. Finally, the bricks were air-cooled in the kiln for 40 days before testing	228 × 114 × 76	Control: ~1300 With WGS: 2% increase with 25% WGS (up to ~1325)	(CS) Control: 9.17 MPa WGS15: 11.25 MPa (23% increase) WGS25: 12.56 MPa (37% increase)	WA: Control: 20.34%. WGS15: 19.07% WGS25: 17.17% Porosity Control: 43.27% WGS15: 39.02% WGS25: 35.28%	Thermal conductivity: 0.53–0.59 W/mK Reduced porosity and water absorption Dense and homogenous microstructure Met ASTM standards for moderate weather resistance Low leaching toxicity	Kazmi et al. (2018)

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TABLE 4 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Glass Waste.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive (CS) and flexural strengths (FS) (MPa)	Water absorption (WA) and porosity	Other properties	Ref.
Recycled glass: 20%, 30%, 40%, 46.2%, and 61%	Dry mixed, then 22.6%–18.9% plasticity water was added and mixture rested for 3 h. Molded, sun-dried for 2 days, and fired in a kiln at 850°C for 36 h. Air-cooled in kiln for 40d	210 × 105 × 90	Control: ~2135 With glass: Decreased	(CS): Control: 47.01 MPa With 46.2% glass: 35.9 MPa Reduction of 5.1%–34.6% with increasing glass content	Control: 43.27%–35% (46.2% glass)	Translucency increased up to 46.2% glass content Alkali-silica reaction Enhanced photocatalytic NOx degradation by 3.1%–17.9% Higher thermal conductivity	Torres de Rosso et al. (2020)
Waste glass: 0%, 5%, 10%, 15%, 20%, and 25%	Mixed in dry form, then wet-mixed with plasticity water (18%–25%). Molded, sun-dried for 2d, and fired in kiln at ~800°C for 36 h, air cooling for 40d	140 × 65 × 40	1760–1700	CS With 0% glass: 9.17 With 15% glass: 11.25 With 25% glass: 12.56	WA 14.78%–18.66% Porosity 29.71%–35.17%	Thermal conductivity: 0.4–0.7 W/mK Enhanced photocatalytic properties Low alkali-silica reaction Good durability and weathering resistance	Jamshidi et al. (2016)
Glass powder 30% Fly ash: 40% Crusher dust: 30%	Mixed with alkaline solution (sodium silicate and sodium hydroxide in ratio 1:2.4), protein-based pre-foam injected at 0.57 MPa, molded, demolded after 12 h, cured at 60°C for 12 h	100 × 100 × 100	Control: 2000 With foam: 1000–1500	CS: Control: 51.6 at 90days With foam: 11.3 at 90d (47.7% foam)	WA 9%–18.33% Porosity 8.79%–33.6%	Thermal conductivity reduced by 77.45% with foam Energy savings of 8.94%–10.47% Improved insulation properties	Singh et al. (2021)

content, which can enhance bonding, matrix cohesion, and elasticity. Materials like recycled PS, expanded perlite, and PPRs have demonstrated moderate to significant increases in flexural strength, especially under controlled firing conditions. However, organic additives such as TW and spent coffee grounds tend to reduce flexural performance at higher concentrations due to the introduction of voids and disruption in particle bonding. This reduction is often in line with decreases observed in compressive and tensile strengths, reflecting the overall weakening of the structural matrix. In contrast, inorganic additives like eggshell powder and mixed plastic wastes (e.g., HDPE, LDPE, PET) have shown improved flexural strength, with some formulations achieving values nearly double that of conventional clay bricks. These results suggest that the type, proportion, and physical interaction of the waste material with the binder matrix are critical in determining flexural performance outcomes.

6 Optimization strategies for MSW-based masonry bricks

The successful integration of MSW into masonry brick production requires systematic optimization approaches to achieve optimal performance while maintaining economic viability and environmental benefits. Mix design optimization represents the most critical factor, where the proportion of MSW to conventional materials must be carefully balanced based on waste type and intended application. Research demonstrates that optimal MSW content typically ranges between 10%–30% by weight, with paper sludge showing peak performance at 15%–20% replacement, plastic waste achieving best results at 10%–15% incorporation, and glass waste effectively utilized up to 25% replacement. The key to successful optimization lies in understanding the individual characteristics of each waste stream and tailoring mix proportions to maximize beneficial properties while mitigating potential drawbacks such as increased porosity or reduced bonding strength.

Processing parameter optimization involves careful control of manufacturing conditions to maximize MSW integration benefits. Critical parameters include firing temperature optimization (900°C–1050°C depending on waste type), moisture content control during curing (85%–95% relative humidity), and article size management (typically 0.5–2.0 mm for optimal packing density). Quality enhancement techniques such as waste pre-processing, surface treatment of hydrophobic materials, and strategic use of binding agents (cement 5%–10%, lime 3%–7%) significantly improve performance outcomes. Economic optimization considerations encompass waste procurement costs, energy consumption during manufacturing, and market acceptance factors, with studies indicating 15%–30% cost savings compared to conventional alternatives when properly optimized. These

TABLE 5 Physico-mechanical properties of masonry units incorporating MSW materials namely: Rubber and Leather.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive strength (CS) and flexural strength (FS)	Water absorption (WA) and porosity	Other properties	Ref.
Crumb rubber (CR) by volume 10%–30%	Automated brick machine with 69 kPa pressure for 5s	Standard brick with 100 mm height	1930.3–1776.5	CS dropped to ~6 at 10% CR with linear decrease to 30% CR	Higher porosity in factory units, increased air bubbles with CR	Dark surface, uniform CR distribution, 4–5 mm height deformation at 25%–30% CR	Sodupe-Ortega et al. (2016)
2%, 4%, 6%, 8%, and 12% buffing dust (leather industry waste), with 4% being optimal	Conventional brick making, mixed with clay and fired in kiln at 1000°C	228 × 115 × 76 mm	Control (0%): 2.49 g/cm3 With buffing dust: Decreased from 2.21 g/cm3 (2%) to 1.2 g/cm3 (12%)	Maximum CS at 4% buffing dust: 12.02 MPa Control brick CS: 10.53 MPa CS decreased with higher buffing dust content	Control: 8.63% WA Increased with buffing dust content 2%: 10.98% 4%: 14.09% 6%: 18.76% 8%: 26.24% 12%: 31.02%	Area shrinkage: 3.96%–12.34% Weight loss on ignition: 4.63%–16.02% Efflorescence: Nil up to 6% buffing dust Good heavy metal stability in leaching tests Dark surface appearance	Milu et al. (2022)
CR: 3%, 6%, 9%, and 12% by volume of fine aggregates PP fibers: 0.1%, 0.2%, 0.3% by volume	Conventional casting with vibration table Water/cement ratio: 0.50 Cement:aggregate ratio: 1:4.66 Curing: 28d	228 × 108 × 75 mm	Control mix: 2018 kg/m3 With CR+0.2% PP: Decreased from 1895 (3% CR) to 1828 (12% CR) kg/m3	CS: Decreased from 19.53 MPa (control) to 12.52 MPa (12% CR) FS: Maximum 5.37 MPa with 0.2% PP fiber, decreased with CR addition Best performance: 6% CR + 0.2% PP fibers	WA: 6.59% (control) increased to 9.2% (12% CR) Initial Rate of Water Absorption: 0.39–0.53 kg/min/m2 Increased porosity with CR	Enhanced impact resistance up to 6% CR Better crack resistance with PP fibers Good sulfate resistance Dark surface appearance with CR content >6%	Thakur et al. (2022)
10%–70% crumb rubber (CR) by volume of fine aggregates in 10% increments	Manual mixing with cement:aggregate ratio 1:4.66 Compacted in steel mold using steel rod Air cured 6 h, demolded, then water cured 28days at 22°C Oven dried 48 h at 65°C	105 × 75 × 225 mm (for most tests) 105 × 100 × 75 mm (for compressive tests)	Control: 2.17 g/cm3 Decreased with CR content from 2.11 g/cm3 (10% CR) to 1.53 g/cm3 (70% CR)	CS: Decreased from 28.7 MPa (control) to 4.4 MPa (70% CR) FS: Decreased from 5.61 MPa (control) to 1.91 MPa (70% CR) Linear relationship between CS and FS, with FS ≈ 1/6 of CS	WA: Increased from 3.05% (control) to 7.41% (70% CR) Porosity: Increased from 6.6% (control) to 11.4% (70% CR)	Improved thermal insulation (5%–11% improvement) Better freeze-thaw resistance with CR Smoother surface finish Higher energy absorption Better workability up to 40% CR	Turgut and Yesilata (2008)
CR: 2.5%, 5%, 7.5%, and 10% by volume Cement: 5% and 10% of soil mass	Clay soil mixed with cement and CR at optimum moisture content Formed using hydraulic compacting machine Cured at room temperature for 28d	240 × 220 × 110 mm	Control: 1549.59 kg/m3 With CR: 1614.15 With 5% cement + CR: 1657.20 With 10% cement + CR: 1743.28	CS Control: 2.84 With 5% cement + CR: 3.79–5.68 With 10% cement + CR: 4.55–6.95 Peak strength at 2.5% CR for both cement contents	Control: 25% WA With CR only: Decreased to 17%–24% WA With cement + CR: Further decreased to 13.3%–20% WA Lowest WA at 7.5% CR + 10% cement	Better surface adhesion between soil and CR with cement Optimal mix: 7.5% cement +6% CR for structural applications	Olofinnade and Adeyinka (2024)

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TABLE 5 (*Continued*) Physico-mechanical properties of masonry units incorporating MSW materials namely: Rubber and Leather.

Waste content (%)	Production method	Unit size (mm)	BD, kg/m^3	Compressive strength (CS) and flexural strength (FS)	Water absorption (WA) and porosity	Other properties	Ref.
Rubber crumbs: 10%, 20%, and 30% of total aggregate weight Fly ash: 20% by weight of total binder (cement + fly ash)	Mixed cement, fly ash, sand, CR and water Manual compression in mold Wet cured for 28d by submerging in water	203.2 × 76.2 × 50.8 mm (8″× 3″× 2″)	(10% CR): 1716.58 (20% CR): 1661.89 (30% CR): 1484.37	CS Mixture 1: 1074.14 ± 52.7 psi (7.41 MPa) Mixture 2: 586.99 ± 30.4 psi (4.05 MPa) Mixture 3: 405.11 ± 35.3 psi (2.79 MPa)	WA Mixture 1: 4.59% ± 0.75% Mixture 2: 5.25% ± 0.91% Mixture 3: 7.20% ± 0.78%	Lighter weight than conventional bricks Poor adhesion between rubber and cement Increased void content with higher rubber content Suitable for non-load bearing applications	Bustamante et al. (2025)
Tannery sludge (TS): 10%, 20%, 30%, and 40% by dry weight of soil	Lab: Mixed, manual compression, fired at 900°C–1000°C for 3 h Field: Made in conventional brick kiln following typical protocols Curing: Air-dried 24 h, oven-dried 48 h at 105°C	120 × 60 × 35 mm (laboratory samples)	Control: 1872 kg/m3 Decreased with TS content from 1687 kg/m3 (10% TS) to 1505 kg/m3 (40% TS) at 1000°C	CS Lab samples: 10.98–29.61 MPa depending on TS content and firing temperature Field samples with 10% TS: 16.3 MPa Strength decreased with increasing TS content	WA increased with TS content 10% TS: 9.1%–14.2% 40% TS: Up to 20.9%	Decreased shrinkage with increased TS content 15%–47% energy savings during firing Low heavy metal leaching No efflorescence Lighter weight than conventional bricks	Juel et al. (2017)
0%–10% tannery solid waste (dried tannery sludge) in 2% increments	Mixed with 15% water hydraulic press (6 MPa pressure) Dried at 50°C (24 h), 80°C (3 h), 110°C (3 h) Fired at 700°C–800°C for 3 h total firing time	50 × 50 × 50 mm (cubic specimens)	Decreased from 2.0 to 1.4 g/cm3 with increasing waste content	CS Maximum at 0% waste: ~20 MPa Decreased with increasing waste content Up to 5% waste content met minimum standard of 8.7 MPa	WA: 12%–28% Cold WA: 10%–24% Boiling WA: 10%–30% Apparent porosity: 25%–39%	Drying shrinkage increased with waste content (up to 0.53%) Firing shrinkage: 0%–1% Lower firing temperature required (700°C sufficient) Lighter weight products	Ghonaim et al. (2020)

systematic approaches ensure that MSW-based masonry units achieve acceptable performance standards while contributing to sustainable construction practices and waste diversion goals.

7 Limitations

The heterogeneity of MSW introduces variability in product quality, requiring thorough sorting and pre-processing methods. Concerns about leachate, long-term durability, and performance under extreme environmental conditions must also be addressed. The scalability of MSW integration into industrial processes is another critical factor, demanding investment in advanced technologies and infrastructure. Moreover, it can be inferred from the case studies that the long-term behaviour of MSW-incorporated construction materials under environmental stresses such as freeze-thaw cycles, chemical exposure, and UV radiation remains insufficiently studied.

8 Future research

Despite the comprehensive review presented, several critical research gaps warrant future investigation to advance MSW integration in masonry brick production. Innovations in waste segregation technologies, such as automated sorting and chemical

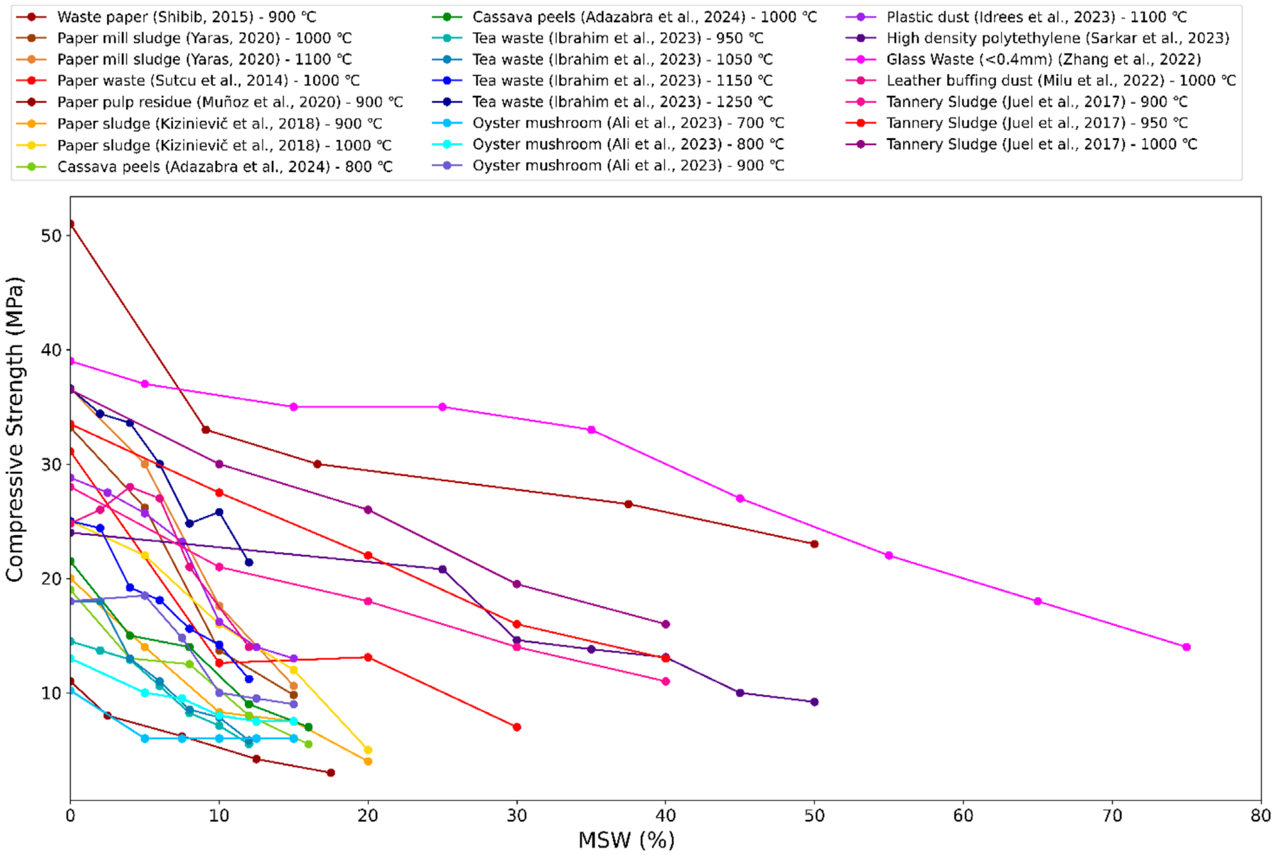

FIGURE 9
Variation of compressive strength of bricks with the addition of MSW concentration.

separation, can improve the purity of MSW inputs, enabling more consistent and high-quality material production. Pre-processing techniques like thermal treatment, pyrolysis, and bio-stabilization can also mitigate raw MSW's variability and contaminant issues. Research into blending MSW with other industrial by-products, such as fly ash, slag, or construction demolition waste, as done by a few researchers, can create synergistic effects that enhance the mechanical and thermal properties of bricks. Tailoring the mix ratios based on intended applications, such as load-bearing or insulation, can maximize material efficiency. Additionally, rigorous LCA is essential to evaluate the environmental benefits and trade-offs of incorporating MSW into construction materials. These assessments should cover all stages of the material's lifecycle, from waste collection and processing to manufacturing, use, and end-of-life disposal. Long-term durability studies exceeding 10 years are essential to establish performance reliability under various environmental conditions. Standardized testing protocols designed for MSW-based construction materials need development to ensure consistent quality assessment. Economic feasibility studies incorporating regional waste management costs, material processing expenses, and market acceptance factors would facilitate commercial implementation. Finally, the development of automated quality control systems for MSW sorting and processing would enhance the consistency and scalability of MSW-based brick production.

9 Conclusion

This review has systematically examined the utilization of various municipal solid waste (MSW) components—including PS, food waste, plastics, rubber, leather, and glass waste—in the development of masonry bricks and blocks. The comprehensive analysis of physico-mechanical properties highlights the following key insights:

BD and Porosity: The inclusion of MSW generally reduces BD due to increased internal porosity, leading to the development of lightweight masonry units. This characteristic is particularly beneficial for non-load-bearing and thermally insulating applications.

Mechanical Performance: Compressive, tensile, and flexural strengths tend to decrease with higher MSW content, especially for organic and fibrous wastes. However, several optimized formulations, particularly those involving treated or inert wastes like glass and select plastics, were found to meet or exceed conventional standards for structural applications.

Water Absorption and Durability: Increased porosity typically results in higher water absorption, which could adversely affect long-term durability. Hydrophobic materials such as plastic waste can mitigate this issue, improving moisture resistance and dimensional stability.

Thermal Properties: A consistent reduction in thermal conductivity was observed across most MSW-integrated masonry units, with some formulations achieving values as low as

0.17 W/mK. This indicates a strong potential for enhanced thermal insulation in energy-efficient construction.

Material Optimization: The performance of MSW-based bricks is highly dependent on the type, proportion, and treatment of the waste materials, as well as the firing or curing process. Optimal mix designs can achieve a balance between sustainability and mechanical performance.

This review confirms the technical feasibility of incorporating MSW into masonry unit production while identifying critical research gaps. Future studies should focus on standardized testing protocols, long-term durability assessments, leachability and environmental safety, and the integration of life cycle assessment (LCA) to validate the environmental benefits. Establishing clear guidelines for waste segregation, processing, and incorporation methods will be essential for the industrial-scale implementation of MSW-derived construction materials.

Author contributions

NN: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft. MA: Data curation, Formal Analysis, Methodology, Visualization, Writing – original draft. SK: Data curation, Formal Analysis, Visualization, Writing – original draft, Writing – review and editing. MM: Validation, Writing – original draft, Writing – review and editing. AA-F: Conceptualization, Methodology, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that Generative AI was used in the creation of this manuscript. The AI was used for rephrasing and English writings enhancement.

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Glossary

ASTM	American society for testing and materials
LDPE	Low-density polyethylene
BD	Bulk density
MPa	Megapascal
CAA	Cashew apple ash
MSW	Municipal solid waste
CF	Cellulose fiber
PMS	Paper mill sludge
CP	Cassava peel
PP	Polypropylene
CR	Crumb rubber
PPR	Paper pulp residue
CS	Compressive strength
PS	Paper sludge
DPMS	Deinking paper mill sludge
PVC	Polyvinyl chloride
EP	Eggshell powder/expanded perlite (context-dependent)
RPS	Recycled paper sludge
EPS	Expanded polystyrene
SCG	Spent coffee grounds
ESA	Eggshell ash
SMM	Spent mushroom material
FS	Flexural strength
SPW	Sludge paper wastewater
FW	Food waste
STS	Split tensile strength
GS	Grape seeds
TW	Tea waste
HDPE	High-density polyethylene
WA	Water absorption
KP	Kaolinitic paper pulp
WL	Wine lees
LCA	Life cycle assessment
WPA	Waste paper aggregate