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PARAMETERS OF BLOCK MANUFACTURING WITH RECYCLED MATERIALS: CRITICAL REVIEW, TAXONOMY OF COMPACTION AND CURING TECHNIQUES, AND THEIR IMPACT ON MECHANICAL PERFORMANCE

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ABSTRACT

The present study analyzed the parameters of the manufacture of blocks made from recycled materials through a systematic and critical review of the scientific literature. Compaction techniques, curing methods and their influence on mechanical performance were specifically evaluated, considering properties such as compressive strength, water absorption and durability. The results showed that the variability in the mechanical behavior of the blocks was mainly due to the lack of standardization in the manufacturing processes, as well as the heterogeneity of the recycled materials used. It was identified that compaction directly influenced the densification of the material and the reduction of porosity, while curing determined the microstructural evolution and the development of mechanical strength. Controlled curing methods, such as wet curing and CO_2 carbonation, were also found to significantly improve block performance compared to ambient curing. In terms of materials, industrial waste showed a more favorable behavior due to its pozzolanic activity, while polymers and organic waste required stricter manufacturing conditions to achieve adequate levels of resistance. Finally, a manufacturing taxonomy and an integrated conceptual model were proposed to understand the interaction

between material, compaction, curing and mechanical performance, providing technical criteria for the optimization of the production process.

KEYWORDS: Recycled Materials, Concrete Blocks, Compaction, Curing, Mechanical Performance.

INTRODUCTION

The construction industry is currently positioned as one of the sectors with the greatest environmental impact globally, due to the high consumption of natural resources and the significant generation of solid waste. In this context, the circular economy emerges as a strategic approach that promotes the reuse and recovery of materials, particularly those from construction and demolition waste, as well as industrial and agro-industrial by-products. The incorporation of these recycled materials in the manufacture of concrete blocks and masonry units represents a viable alternative to reduce the pressure on natural resources and mitigate the environmental impacts associated with the final disposal of waste (Hossain et al., 2020; Junkes et al., 2024).

In recent years, several studies have explored the use of recycled aggregates, plastic waste, industrial ash, and other secondary materials in the production of blocks, evidencing their potential for structural and non-structural applications. Recent research highlights significant advances in terms of sustainability and technical performance (Asif & Javed, 2024; Farooq et al., 2023; Juan-Valdés et al., 2018). However, the results obtained show a high variability in mechanical properties, especially in compressive strength, durability and water absorption, which limits its adoption on an industrial scale (Roknuzzaman & Rahman, 2024; Othman et al., 2025).

This variability is largely associated with the lack of control and standardization in manufacturing parameters, particularly in the compaction and curing stages. Compaction, understood as the process by which the mixture is densified to reduce voids and improve internal cohesion, depends on variables such as the pressure applied, the compaction method and the moisture content. Curing, on the other hand, directly influences the development of the microstructure and the hydration or chemical activation reactions, being decisive in the evolution of the mechanical properties of the material (Zhan et al., 2016; Mastali et al., 2018).

Several studies show that small variations in these processes can generate significant differences in the final performance of the blocks. For example, accelerated CO_2 curing and controlled compaction techniques have shown substantial improvements in the mechanical strength and durability of recycled materials, although with results depending on the type of waste and experimental conditions (Zhan et al., 2013; Merino-Lechuga et al., 2025). Likewise, research on stabilized blocks and composite materials highlights the strong influence of manufacturing conditions on structural behavior (Bouhiyadi et al., 2025; Valenzuela et al., 2024).

Despite these advances, the current literature lacks an integrative framework that systematizes and critically compares compaction and curing techniques applied to blocks with recycled materials. Most studies focus on specific cases or particular conditions, which makes it difficult to extrapolate results and define standardized technical criteria (Sabai et al., 2013; Soutsos et al., 2011). This fragmentation of knowledge represents an important gap for the consolidation of sustainable technologies in the construction industry.

From a technical perspective, beyond the environmental approach, it is essential to understand how manufacturing parameters affect the internal structure of the material and, therefore, its mechanical behavior. The optimization of these parameters not only improves the quality of the final product, but also guarantees its technical, economic, and regulatory feasibility, key aspects for its implementation in real projects (Narayanaswamy et al., 2020; Kumar Chilukuri et al., 2023).

In this context, the objective of this study is to critically analyze the compaction and curing techniques used in the manufacture of blocks with recycled materials, evaluating their influence on mechanical performance and proposing an integrative technical taxonomy.

METHODOLOGY

The present study was developed under a systematic review approach with comparative critical analysis, aimed at identifying, evaluating and synthesizing the scientific evidence related to the parameters of manufacturing in blocks made with recycled materials, with emphasis on compaction techniques, curing methods and their influence on mechanical performance.

This approach made it possible not only to collect relevant information, but also to analyse the cause-effect relationships between manufacturing variables and mechanical properties, overcoming the merely descriptive nature of traditional reviews and providing an integrative view of the process.

Additionally, the study was framed in the research project entitled; ***"Evaluation of the quality of the solids of the pre-sedimentation pool of the drinking water treatment plant for the elaboration of aggregate block"***, which provided the technical and conceptual context for the analysis of the materials and processes evaluated.

Bibliographic search strategy

The search for information was carried out in high-impact scientific databases, including:

Scopus; Web of Science; ScienceDirect.

Structured search strings with Boolean operators were used, combining terms related to recycled materials, concrete blocks, compaction, curing, and mechanical performance.

Example of string used:

("recycled materials" OR "recycled aggregates") AND ("concrete blocks" OR "masonry blocks") AND (compaction OR curing) AND ("mechanical strength" OR "compressive strength")

The search was limited to publications between 2011 and 2026, in order to include both baseline studies and recent high-impact research.

Inclusion and exclusion criteria

Inclusion criteria:	Exclusion criteria:
• Experimental studies on blocks with recycled materials • Research that analyzes compaction, curing, or mechanical properties • Articles in indexed journals • Publications in English and Spanish	• Studies without experimental validation • Articles not directly related to blocks or masonry • Duplicate documents • Investigations without quantifiable mechanical results

Study Selection Process (PRISMA)

The selection process was carried out following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, structured in four phases:

- Identification: Initial collection of articles
- Screening: deduplication and review of titles/abstracts
- Eligibility: full-text evaluation
- Inclusion: final selection of relevant studies

Figure 1 shows the study selection process, showing the progressive reduction in the number of articles from initial identification to final inclusion, guaranteeing the quality and relevance of the information analyzed.

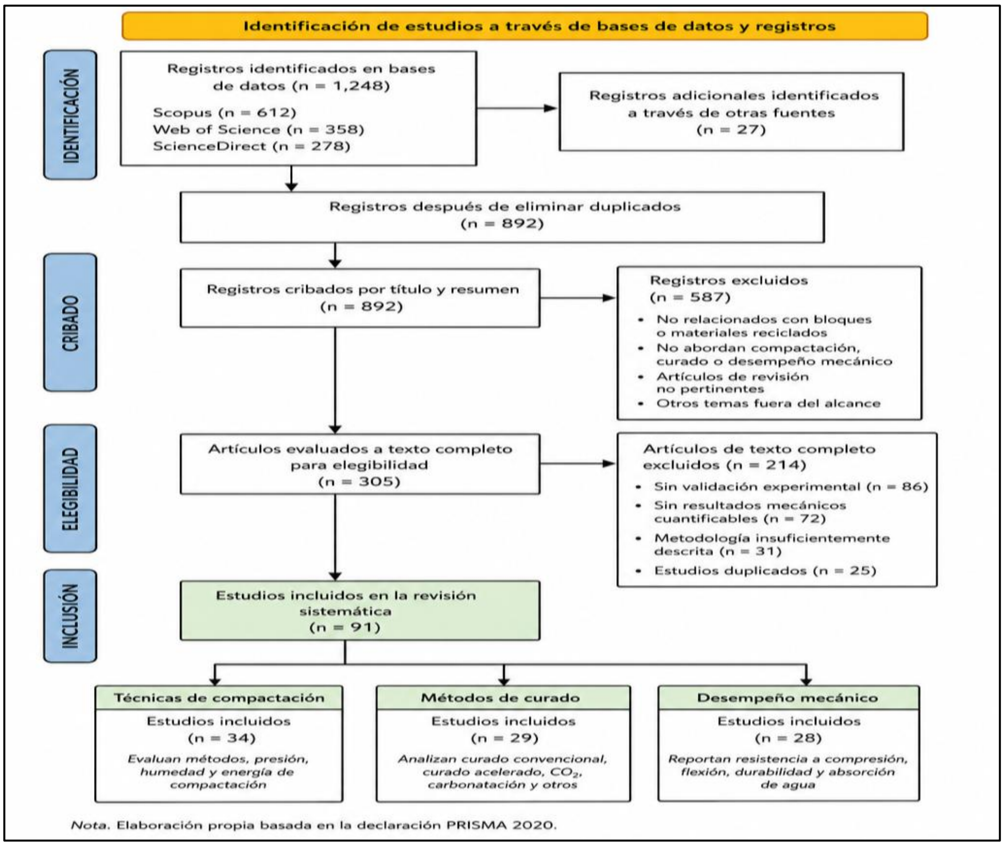

Figure 1. PRISMA Flowchart of the Study Selection Process

Note: in original language (Spanish)

Data extraction and organization

To systematize the information collected, a data extraction matrix was developed that allows comparing the manufacturing parameters and their relationship with the mechanical performance of the blocks with recycled materials.

Table 1 presents the systematization of the studies analyzed, allowing the identification of patterns, methodological differences and trends in manufacturing parameters and their relationship with mechanical performance.

Table 1. Extraction matrix and comparison of manufacturing parameters and mechanical performance

Author/Year	Recycled material	Block Type	Compaction technique	Curing method	Key Parameters	Mechanical properties evaluated	Main findings
Sabai et al. (2013)	Construction and demolition waste (CDW)	Concrete Blocks	Vibrocompaction	Wet Curing	Water/cement ratio, compaction pressure	Compressive Strength	Moderate improvement in strength with adequate compaction
Soutsos et al. (2011)	Recycled aggregate	Structural Blocks	Mechanical compaction	Standard Curing	Replacement Percentage	Strength, density	Reduced drag with high recycled contents
Farooq et al. (2023)	100% recycled aggregate	Paver blocks	Pressing compaction	Wet Curing	Compaction pressure, moisture content	Strength, durability	High strength with proper compaction control
Asif & Javed (2024)	Recycled Plastic	Paver blocks	Thermal/mechanical compaction	Environmental Curing	Plastic Ratio	Resistance, environmental impact	Optimal balance between strength and sustainability
Juan-Valdés et al. (2018)	Recycled ceramic waste	Non-structural prefabricated	Mechanical compaction	Wet Curing	Particle size	Strength, microstructure	Significant influence on microstructure and strength
Junkes et al. (2024)	Industrial and construction waste	Eco-friendly blocks	Vibrocompaction	Wet Curing	Waste dosing	Strength, absorption	Reduced absorption with better compaction
Mastali et al. (2018)	Ashes and alkaline materials	Mortars/blocks	Manual compaction	CO_2 Curing	Curing time, CO_2 concentration	Strength, durability	Significant increase in CO_2 resistance
Zhan et al. (2013)	Recycled aggregate	Concrete Blocks	Vibrocompaction	CO_2 Curing	Pressure, exposure time	Compressive Strength	Noticeable improvement in strength and densification
Zhan et al. (2016)	Recycled aggregate	Concrete Blocks	Controlled compaction	CO_2 Curing	Curing parameters	Strength, microstructure	High sensitivity to curing conditions
Bouhiyadi et al. (2025)	Wood ash	Compressed Earth Blocks	Mechanical Pressing	Natural curing	Stabilizer Content	Thermal and mechanical resistance	Improved thermo-mechanical properties
Valenzuela et al. (2024)	Industrial by-products	Compressed blocks	Mechanical compaction	Controlled curing	Compaction Energy	Strength, energy efficiency	Structural Performance Optimization
Othman et al. (2025)	Fine recycled aggregate	Interlocking blocks	Vibrocompaction	Wet Curing	% replacement	Compressive Strength	Variable results according to dosage
Roknuzzaman & Rahman (2024)	Recycled aggregate	Recycled concrete	Conventional compaction	Standard Curing	Chemical exposure	Strength, durability	Decreased resistance in aggressive environments
Merino-Lechuga et al. (2025)	Recycled aggregate	Permeable blocks	Mechanical compaction	CO_2 Curing	Curing Type	Resistance, sustainability	CO_2 improves performance and reduces environmental footprint
Narayanaswamy et al. (2020)	Stabilized Earth	Ground Blocks	Manual/mechanical compaction	Natural curing	Compaction Energy	Strength, Thermal Properties	High compaction dependence

As can be seen, there is a marked variability in compaction and curing methods, which directly influences the mechanical properties of the materials. Clear trends towards the use of vibrocompaction and CO_2 curing are identified as strategies to improve strength and durability.

Analysis of information

The analysis was developed through a comparative and critical approach, in which the following were identified:

- Trends in compaction techniques
- Effects of Healing Methods
- Relationship between manufacturing variables and mechanical properties
- Gaps and contradictions in literature

This analysis made it possible to establish a basis for the construction of a technical manufacturing taxonomy, as well as the identification of critical parameters that influence the structural behavior of blocks with recycled materials.

RESULTS

Sorting Recycled Materials

The literature analysis allowed to identify and classify the recycled materials used in the manufacture of blocks into four main categories: construction and demolition waste, recycled polymers, industrial waste and organic or agro-industrial waste. This classification facilitated the understanding of the physical-chemical properties of materials and their influence on manufacturing parameters and mechanical performance.

Construction and demolition waste (CDW), particularly recycled aggregates (RCA), represented the most widely studied category. Various studies have shown their application in structural and non-structural blocks, highlighting their availability and compatibility with cementitious matrices (Soutsos et al., 2011; Farooq et al., 2023). However, it was observed that the quality of the recycled aggregate, its porosity, and the presence of adhered mortar negatively influenced mechanical strength, especially when high substitution percentages were used (Roknuzzaman et al., 2025; Othman et al., 2025).

In relation to recycled polymers, particularly plastics, studies showed their use as a material for partial or total substitution of fine aggregates in paver-type blocks. These materials provided benefits in terms of density reduction and improved workability, although they presented limitations in compressive strength when compaction conditions were not optimized (Asif & Javed, 2024). Likewise, its behavior depended to a large extent on the distribution of the polymer in the matrix and the manufacturing process.

On the other hand, industrial waste, such as fly ash, slag and by-products of chemical processes, showed a high potential as supplementary cementitious materials or stabilizers. The studies analyzed showed that these materials contributed significantly to the development of mechanical strength and durability, especially when combined with advanced curing techniques such as CO_2 carbonation (Mastali et al., 2018; Merino-Lechuga et al., 2025). In addition, it was observed that their chemical reactivity favored the formation of denser and more compact matrices.

Finally, organic and agro-industrial waste, such as wood ash and plant waste, were mainly used in compressed earth blocks and alternative materials. These materials showed improvements in thermal properties and density reduction, although with variable mechanical behavior that depended on the type of stabilization and compaction conditions (Bouhiyadi et al., 2025; Valenzuela et al., 2024). Its application was mainly oriented towards sustainable solutions in low and medium load constructions.

In general terms, it was evident that each type of recycled material presented particular characteristics that directly influenced the compaction and curing processes, as well as the final mechanical performance. This heterogeneity was a determining factor in the variability of results reported in the literature, which reinforces the need to establish standardized technical criteria.

For a better understanding of the diversity of materials used in the manufacture of blocks with recycled content, a structured classification of the main types identified in the literature is presented.

Figure 2. Sorting recycled materials into blocks

Note: in original language (Spanish)

Figure 2 showed that the recycled materials used in the manufacture of blocks were grouped into four main categories, each with differentiated physical-chemical characteristics and mechanical behaviors.

It was observed that construction and demolition waste constituted the most used base due to its availability and compatibility with cementitious matrices, although its porosity and heterogeneity negatively affected water absorption and mechanical strength when manufacturing processes were not controlled. On the other hand, recycled polymers contributed to the reduction of density and improved workability, although they could compromise resistance if their dosage was not optimized.

In contrast, industrial waste showed a more favorable behavior in mechanical terms due to its pozzolanic activity and cementitious capacity, which favored the formation of denser matrices. On the other hand, organic waste provided thermal and sustainability benefits, although its structural performance depended on adequate stabilization processes.

Additionally, it was evidenced that the impact of these materials was not independent, but was closely related to the compaction and curing processes, which determined key properties such as mechanical resistance, durability and water absorption. In this sense, the selection of recycled material, together with the optimization of the manufacturing parameters, was a critical factor for the final performance of the blocks.

Compaction techniques

The analysis of the literature showed that compaction was one of the most influential parameters in the manufacture of blocks with recycled materials, due to its direct effect on the density, porosity and internal cohesion of the matrix. It was observed that the variability in compaction methods and operating parameters represented one of the main causes of dispersion in the reported mechanical results.

Types of compaction

Four main compaction techniques used in the manufacture of blocks from recycled materials were identified:

Manual compaction was mainly used in small-scale experimental studies and in the manufacture of compressed earth blocks. This method presented significant limitations in terms of uniformity and density control, generating high variability in mechanical results (Narayanaswamy et al., 2020).

Vibrocompaction has positioned itself as one of the most widely used techniques at an industrial level, especially in conventional and recycled concrete blocks. This method allowed for better particle redistribution and void reduction, favoring the densification of the material (Sabai et al., 2013; Junkes et al., 2024).

Hydraulic pressing showed greater efficiency in the generation of blocks with high density, by applying controlled pressures that favored uniform compaction. Recent studies showed that this technique allowed higher mechanical strengths to be achieved, especially in blocks with high recycled material content (Farooq et al., 2023).

On the other hand, dynamic compaction was less reported, but showed potential in specific applications where an energy redistribution of the material was required, particularly in systems with heterogeneous mixtures.

Key Compaction Variables

The analysis allowed us to identify three critical variables that directly influenced the effectiveness of the compaction process:

The pressure applied was the most determining factor in the densification of the material. It was observed that increases in pressure generated a significant reduction in porosity and an increase in compressive strength, although with a non-linear behavior in some cases (Zhan et al., 2016).

Compaction time influenced particle redistribution and mixture stability. Insufficient times generated heterogeneous structures, while excessive times did not always represent significant improvements in mechanical performance.

Moisture content was identified as a critical parameter for workability and effective compaction. Optimal levels of humidity facilitated cohesion between particles, while out-of-range values caused structural defects, such as cracking or low density (Valenzuela et al., 2024).

To analyze the influence of compaction on the mechanical performance of the blocks, a general relationship between the applied pressure and the resistance obtained is presented.

Figure 3 showed that the relationship between compaction pressure and the mechanical resistance of the blocks presented a non-linear behavior, characterized by three clearly differentiated stages.

In the first phase, at low pressures, a significant increase in compressive strength was observed associated with the rearrangement of particles and the initial reduction of voids. At this stage, compaction favored contact between the components of the mixture, increasing the internal cohesion of the material.

In a second phase, corresponding to intermediate pressures, there was a more efficient densification of the system, where the reduction of internal porosity and the improvement in the particle size distribution contributed to a progressive increase in mechanical resistance. This stage represented the optimal compaction range, in which the material reached a balance between density and structural stability.

However, in a third phase, at high pressures, a phenomenon of saturation in resistance was evidenced, where additional increases in pressure generated marginal improvements. This behavior was attributed to the system reaching its maximum possible densification, limiting the internal rearrangement capacity of the particles. In some cases, excessive pressures could even induce microcracking or segregation of components, negatively affecting mechanical performance.

Additionally, it was observed that the response to compaction pressure depended on the type of recycled material. Materials with pozzolanic activity, such as ash and slag, performed better due to their ability to form denser and more reactive matrices. In contrast, recycled polymers showed a lower strength gain, due to their low stiffness and limited adhesion in the cementitious matrix. On the other hand, stabilized organic materials presented the most limited behavior, associated with their less structural nature.

These results confirmed that compaction pressure is a critical parameter in the manufacture of blocks with recycled materials; however, its optimization requires simultaneously considering the type of material, the moisture content and the curing conditions, avoiding the application of excessive pressures that do not generate significant structural benefits.

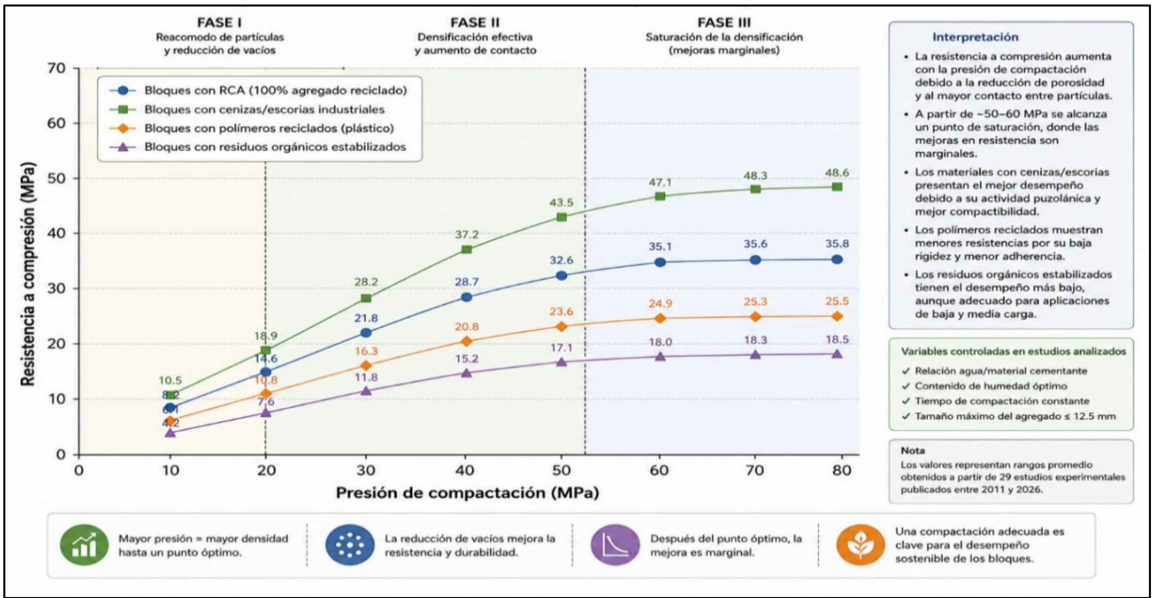

Figure 3. Relationship between compaction pressure and mechanical strength

Note: in original language (Spanish)

Critical analysis

From a critical perspective, it was identified that compaction cannot be analyzed in isolation, since its effect depends on the interaction with other parameters such as the type of recycled material and the curing method.

It was evidenced that a higher density, a product of efficient compaction, generally translated into better mechanical properties; however, in highly porous or low-quality materials, this effect was limited. Likewise, recurrent problems were identified in the literature, such as:

- Lack of standardization in the pressure levels applied
- Lack of moisture content control
- Variability in compaction methods
- Poor comparability between studies

These factors contributed to the dispersion of results and made it difficult to generate reliable predictive models. In this regard, it was concluded that compaction optimization requires a comprehensive approach that simultaneously considers material type, manufacturing conditions, and performance objectives.

Curing Methods

The analysis of the literature showed that the curing process was a determining factor in the development of the mechanical properties of the blocks with recycled materials, due to its direct influence on the hydration of the cement, the activation of supplementary materials and the evolution of the microstructure. It was observed that, even with similar compaction conditions, variations in the curing method generated significant differences in compressive strength and durability.

Types of curing

Four main curing methods applied in the manufacture of blocks with recycled materials were identified:

- Wet curing was the most widely used method, characterized by maintaining high humidity conditions that favored the continuous hydration of the cement. This method showed consistent results in terms of mechanical strength development, especially in systems with recycled aggregates (Farooq et al., 2023; Othman et al., 2025).
- Steam curing was employed to speed up the hydration process through the use of elevated temperatures and controlled environments. This method allowed higher initial resistances to be achieved in less time, although its application depended on controlled conditions and higher energy consumption.
- Accelerated curing, particularly by carbonation with CO_2, showed outstanding results in improving mechanical properties and densification of the matrix. Studies showed that this method favored the formation of stable compounds, reducing porosity and increasing compressive strength (Zhan et al., 2016; Merino-Lechuga et al., 2025).
- Environmental curing was used under natural conditions without specific humidity or temperature control. This method presented a greater variability in the results, due to its dependence on climatic factors, which limited its reproducibility.

Key Variables of Curing

The performance of the curing process was conditioned by three main variables:

Temperature directly influenced the rate of hydration and chemical activation reactions. It was observed that high temperatures accelerated the development of initial resistance, although in some cases they affected the formation of denser structures in the long term.

Curing time was identified as a critical factor in the evolution of mechanical properties. Insufficient curing periods limited the development of endurance, while adequate times allowed for more complete hydration and better internal cohesion.

Relative humidity played a key role in the continuity of chemical reactions. Adequate humidity levels prevented premature drying of the material, favoring the formation of stable hydration products (Mastali et al., 2018).

To evaluate the influence of different curing methods on the mechanical performance of blocks, a general comparison of their effect on compressive strength is presented.

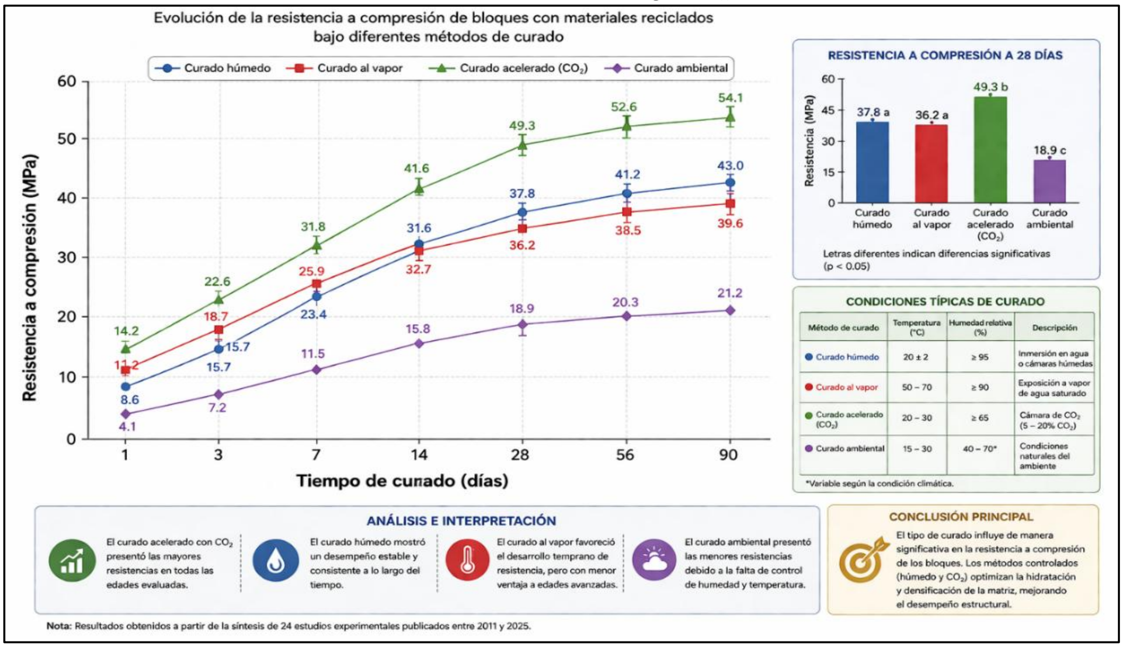

Figure 4. Effect of the curing type on compressive strength

Note: in original language (Spanish)

Figure 4 showed that the curing method had a decisive influence on the evolution of the compressive strength of the blocks with recycled materials, evidencing differentiated behaviors both at early and long-term ages.

In general terms, accelerated curing with CO_2 presented the highest resistance values in all the ages evaluated. This behavior was attributed to early carbonation, which favored the formation of stable compounds (mainly calcium carbonates) and a rapid densification of the matrix, reducing porosity and improving interfacial adhesion between components.

Wet curing showed progressive and stable performance, with continuous increases in strength over time. This behavior was explained by the constant availability of water, which allowed a sustained hydration of the cement and the gradual development of hydration products, resulting in a more homogeneous microstructure.

On the other hand, steam curing showed an advantage at an early age, due to the effect of high temperature on the acceleration of hydration reactions. However, this advantage tended to decline at later ages, suggesting that early accelerated development does not always translate into proportional improvements in the long term.

In contrast, the environmental curing presented the lowest resistance values and the greatest dispersion in the results. This behavior was associated with the lack of control of critical variables such as relative humidity and temperature, which limited the continuity of hydration reactions and favored the formation of less dense structures.

Additionally, it was evidenced that the efficiency of the curing method was conditioned by the type of recycled material used. In particular, systems that incorporated materials with pozzolanic activity responded more favorably to controlled curing methods, while more heterogeneous or low-reactive materials showed lower sensitivity to improvements in curing conditions.

These results confirmed that curing is a critical parameter in the manufacture of blocks with recycled materials, not only because of its influence on mechanical strength, but also because of its ability to modify the microstructure of the material. In this sense, the selection of an appropriate curing method, in combination with optimal compaction conditions, is essential to maximize the structural performance of the blocks.

Mechanical Performance

The mechanical performance of the blocks with recycled materials was evaluated mainly based on three properties: compressive strength, water absorption and durability. The analysis showed that these properties did not depend only on the type of recycled material incorporated, but also on the interaction between compaction, curing, dosage and quality of the waste used.

Properties evaluated

Compressive strength was the most reported property in the studies analyzed, due to its importance in determining the structural or non-structural viability of the blocks. It was observed that blocks made from recycled aggregates were able to achieve acceptable performance when compaction, water/cement ratio, and curing method were adequately controlled (Soutsos et al., 2011; Farooq et al., 2023; Othman et al., 2025). However, the results decreased when high percentages of substitution without prior treatment of the recycled aggregate were used, due to the greater porosity and absorption of the material (Roknuzzaman & Rahman, 2024; Roknuzzaman et al., 2025).

Water absorption was a critical indicator of quality, as it was directly related to the internal porosity of the block. The studies showed that poor compaction increased the number of voids, favoring higher levels of absorption and lower dimensional stability. In contrast, the use of controlled compaction and proper curing contributed to reduced pore connectivity and improved matrix density (Zhan et al., 2013; Zhan et al., 2016).

Durability was evaluated by resistance to aggressive agents, environmental cycles, chemical exposure and long-term stability. Advanced curing methods, especially CO_2 carbonation, were found to improve microstructural densification and reduce the material's vulnerability to external conditions (Mastali et al., 2018; Merino-Lechuga et al., 2025).

Cause-effect relationship

The analysis allowed establishing a direct relationship between compaction and mechanical strength. A higher compaction pressure favored the reduction of voids, the increase in density and the contact between particles, which translated into better compressive strength values. However, this relationship presented a non-linear behavior, since after an optimal range additional increases in pressure generated marginal improvements and even possible internal defects.

Similarly, a significant relationship between curing and durability was evidenced. Controlled curing methods favored hydration, carbonation or chemical activation of recycled materials, allowing for more compact and resistant matrices. In contrast, environmental curing produced more variable results, due to the lack of control over relative humidity and temperature.

Overall, the results showed that mechanical performance was not a consequence of a single variable, but of the interaction between the type of waste, the compaction applied and the curing method used. Therefore, the manufacture of blocks with recycled materials requires an integrated design approach, where each parameter is adjusted according to the available material and the intended use of the block.

Table 2. Comparison of manufacturing parameters and mechanical results.

Author/Year	Recycled material	Block Type	Compaction	Curing	Properties evaluated	Main mechanical result
Soutsos et al. (2011)	Demolition Recycled Aggregate	Concrete Blocks	Mechanical compaction	Standard Curing	Strength and density	Increased recycled aggregate partially reduced strength
Sabai et al. (2013)	RCD	Concrete Blocks	Vibrocompaction	Wet Curing	Compressive Strength	Adequate compaction made it possible to obtain technically viable blocks
Zhan et al. (2013)	Recycled aggregate	Concrete Blocks	Vibrocompaction	CO_2 Curing	Strength and absorption	CO_2 curing improved strength and densification
Juan-Valdés et al. (2018)	Recycled ceramic aggregates	Non-structural prefabricated	Mechanical compaction	Wet Curing	Strength and microstructure	The ceramic residue modified the microstructure and performance
Mastali et al. (2018)	Alkaline waste and recycled aggregates	Alternative mortars/blocks	Conventional compaction	Accelerated CO_2 curing	Strength and durability	Accelerated carbonation improved mechanical performance
Farooq et al. (2023)	100% recycled aggregate	Paver blocks	Pressing/Compression	Wet Curing	Strength and durability	Good performance was achieved with compaction control
Asif & Javed (2024)	Recycled Plastic	Paver blocks	Thermal/mechanical compaction	Environmental Curing	Resilience, cost and environmental impact	There was a sweet spot between plastic content and performance
Junkes et al. (2024)	Construction and chemical industry waste	Eco-friendly blocks	Vibrocompaction	Wet Curing	Strength and absorption	Waste recovery was feasible with controlled dosing
Valenzuela et al. (2024)	Industrial and agro-industrial by-products	Compressed Earth Blocks	Mechanical compaction	Controlled curing	Strength and efficiency	Compaction energy influenced final performance
Bouhiyadi et al. (2025)	Wood ash	Compressed Earth Blocks	Mechanical Pressing	Natural curing	Thermo-mechanical properties	Stabilization improved mechanical and thermal behavior
Othman et al. (2025)	Fine recycled aggregate	Interlocking blocks	Vibrocompaction	Wet Curing	Compressive Strength	Partial replacement presented acceptable results according to dosage
Merino-Lechuga et al. (2025)	Recycled aggregates	Permeable blocks	Mechanical compaction	CO_2 Curing	Resilience and sustainability	CO_2 curing improved strength and reduced environmental impact

Table 2 showed that the best mechanical results were associated with controlled manufacturing processes, especially when mechanical compaction or pressing techniques were combined with wet or accelerated CO_2 curing methods. Studies using recycled aggregates showed that these materials could be used in concrete blocks and pavers as long as dosage, moisture, and compaction were controlled.

Likewise, it was observed that industrial waste presented relevant technical advantages due to its cementitious or pozzolanic activity, while recycled polymers and organic waste required greater control in dosing to avoid significant reductions in resistance. Consequently, the variability of mechanical performance was directly related to the lack of standardization of manufacturing parameters.

In critical terms, the evidence showed that the manufacture of blocks with recycled materials should not be evaluated only from the replacement of natural materials, but from the integral optimization of the production process. The interaction between compaction, curing and type of residue determined the strength, absorption and final durability of the block.

DISCUSSION

The evidence analyzed shows that the performance of blocks with recycled materials does not depend only on the percentage of substitution of the natural material, but also on the interaction between type of waste, compaction, curing and moisture control. This pattern is repeated in studies with recycled aggregates, industrial waste, polymers and agro-industrial materials, where the best results appear when the manufacturing process is controlled and not when a greater amount of waste is simply incorporated.

A first pattern identified is that recycled aggregates from construction and demolition have high technical feasibility, but also greater variability. This variability is explained by the presence of adhered mortar, greater water absorption, particle size differences and heterogeneity of the residue. Therefore, while some studies report blocks with acceptable mechanical performance, others show significant reductions in strength when the replacement of the natural aggregate is high or when there is no prior treatment of the recycled material (Soutsos et al., 2011; Farooq et al., 2023; Othman et al., 2025).

A second pattern relates to industrial waste, such as ash, slag and materials with pozzolanic activity. These residues tend to behave more favourably because they participate in chemical reactions that densify the matrix and improve strength. However, its performance depends on the chemical composition, fineness, dosage and curing method. In this sense, the most consistent results appear when these residues are combined with controlled curing or accelerated carbonation (Mastali et al., 2018; Merino-Lechuga et al., 2025).

Important contradictions are also identified. Some studies argue that the increase in recycled material reduces mechanical strength, while others show that it is possible to achieve adequate performance even with high substitution percentages. This apparent contradiction is not only explained by the type of waste, but also by the differences in manufacturing parameters. Controlled compaction, optimal moisture content and proper curing allow to partially compensate for the negative effects of porosity and heterogeneity of the recycled material.

The compaction-curing interaction is the critical axis of mechanical performance. Efficient compaction reduces voids and improves particle-to-particle contact; However, if the curing is poor, the matrix does not fully develop its hydration or carbonation products. Conversely, advanced curing does not fully compensate for inadequate compaction. Therefore, both processes should be understood as interdependent variables and not as isolated stages.

From a regulatory point of view, the studies reviewed usually use compressive strength, absorption and durability tests compatible with standards such as ASTM C90, ASTM C140, ASTM C39 and UNE-EN 771, applicable to masonry units, concrete blocks and mechanical evaluation of cementitious materials. However, comparison between studies is difficult because not all studies report the same test parameters, cure ages, sample dimensions, environmental conditions or regulatory acceptance criteria.

This lack of standardization represents one of the main limitations of the field. The available literature shows that there are important advances in sustainability and waste recovery, but there is still no uniform technical protocol that allows direct comparison of the results. Therefore, rather than discussing whether a waste is "suitable" or "unsuitable", the discussion should focus on what manufacturing conditions allow that waste to be transformed into a technically reliable block.

Consequently, the main critical contribution of this review is to recognize that the manufacture of blocks with recycled materials requires moving from a material substitution-based approach to a process design-based approach. This involves defining minimum criteria for waste selection, pre-treatment, compaction pressure, optimal humidity, type of curing and regulatory verification. Only under this logic is it possible to reduce mechanical variability and move towards real applications in the construction industry.

PROPOSAL

The present research not only synthesized the existing evidence, but also proposed an integrative approach to the manufacture of blocks with recycled materials, based on the systematic relationship between material type, compaction parameters, curing conditions and mechanical performance. This contribution responds to the identified need to overcome the fragmentation of the literature and move towards standardized technical criteria.

Taxonomy of Block Making with Recycled Materials

Based on the comparative analysis, a manufacturing taxonomy was proposed that organizes the process into four interdependent dimensions:

1. Type of recycled material

- RCD / RCA → High availability, high variability
- Polymers → Low density, lower strength
- Industrial waste → High reactivity, better performance
- Organic waste → Thermal improvement, lower structural capacity

2. Compaction technique

- Manual → Low Uniformity
- Vibrocompaction → Standard Industrial Use
- Hydraulic Pressing → High Densification
- Dynamic Compaction → Specific Applications

3. Curing Method

- Wet → Stability and Reliability
- Steam → Early Endurance
- CO_2 (accelerated) → High mechanical efficiency
- Environmental → High variability

4. Mechanical result

- Compressive Strength
- Water Absorption
- Durability

This taxonomy allows us to understand that final performance does not depend on an isolated variable, but on the optimal combination between these four dimensions.

Based on the findings obtained, a conceptual model is proposed that integrates the main factors that influence the manufacture and performance of blocks with recycled materials.

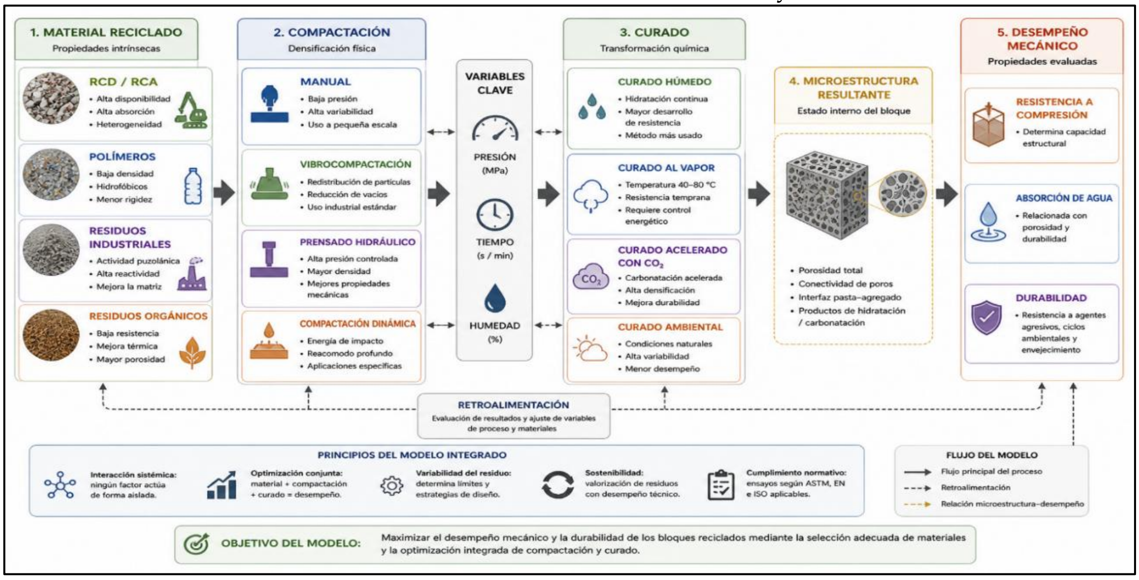

Figure 5. Integrated Recycled Block Manufacturing Model
Note: in original language (Spanish)

Figure 5 represented an integrated model of block manufacturing with recycled materials, in which a systemic relationship was established between the type of material, compaction techniques, curing methods and final mechanical performance. This model made it possible to conceptualize the production process as an interdependent system, in which each variable directly or indirectly influences the quality of the block.

First, the model showed that the recycled material is the main input variable, since its intrinsic properties such as porosity, granulometry, absorption and chemical composition condition the behavior of the system. Materials such as construction waste exhibit high variability, while industrial waste offers greater chemical stability and reactivity.

Compaction was then represented as a process of physical densification, in which variables such as applied pressure, time and moisture content determine the reduction of voids and the degree of contact between particles. Techniques such as hydraulic pressing and vibrocompaction favor the formation of denser structures, while manual methods generate greater heterogeneity.

Curing, on the other hand, was interpreted as a process of chemical transformation that influences the microstructural evolution of the material. Methods such as wet curing and CO_2 carbonation allow the development of hydration or carbonation products that improve internal cohesion, while environmental curing has limitations due to the lack of variable control.

The model integrated these stages through the concept of the resulting microstructure, understood as the internal state of the material, where critical parameters such as porosity, void connectivity and the paste-aggregate interface are defined. This microstructure acts as the bridge between the manufacturing processes and the mechanical behavior of the block.

Finally, mechanical performance was represented through properties such as compressive strength, water absorption and durability, which emerge as a result of the interaction between the previous variables. In this sense, the model showed that there is no simple direct relationship between recycled material and performance, but a chain of interdependent processes.

A key aspect of the model was the incorporation of a feedback mechanism, which allows manufacturing parameters to be adjusted based on the results obtained. This approach reflects the need for continuous optimization in the production of recycled blocks, considering the inherent variability of materials.

Overall, Figure 5 demonstrated that block fabrication with recycled materials must be approached from a holistic approach, where material selection, compaction optimization, and cure control are articulated to maximize mechanical performance. This model constitutes a conceptual contribution that facilitates technical decision-making and the design of more efficient and sustainable processes in the construction industry.

LIMITATIONS AND FUTURE RESEARCH

The present study presented some limitations inherent to the type of systematic review developed. First, the availability of information was conditioned by the heterogeneity of the studies analyzed, which used different methodologies, recycled materials, compaction conditions, and curing methods. This variability made it difficult to directly compare results and generalize conclusions.

Second, a lack of standardization in the experimental protocols was evidenced, especially in critical variables such as compaction pressure, moisture content, curing conditions and test ages. This situation limited the possibility of establishing universal optimal ranges applicable to all types of recycled materials.

In addition, most studies focused on laboratory conditions, with little validation at full scale or in industrial settings. This represents a major gap between academic research and its practical implementation in the construction industry.

In terms of future research, it is recommended:

- Develop standardized experimental protocols that allow results to be compared between studies
- Evaluate the behavior of recycled blocks under real service conditions
- Deepen the analysis of the microstructure using advanced techniques (SEM, XRD, CT-scan)
- Investigate the integration of AI-based predictive models to optimize manufacturing parameters
- Analyze long-term performance considering durability, aging, and environmental exposure
- Studying technical and economic feasibility on an industrial scale

These lines of research will allow progress towards the consolidation of more reliable and sustainable technologies in the manufacture of blocks with recycled materials.

CONCLUSIONS

The present study critically analyzed the parameters of block manufacturing with recycled materials, focusing on compaction techniques, curing methods and their influence on mechanical performance.

It was evident that the performance of the blocks did not depend exclusively on the type of recycled material, but on the interaction between the manufacturing variables. In this sense, compaction was identified as the main mechanism of physical densification, while curing was decisive in the evolution of the microstructure and in the development of mechanical resistance.

The results showed that construction and demolition waste was the most used alternative, although with high variability in performance due to its heterogeneity. On the other hand, industrial waste presented better mechanical results, associated with its pozzolanic activity and cementitious capacity. In contrast, polymers and organic waste required greater control in dosing and manufacturing parameters to achieve adequate levels of performance.

It was determined that there is an optimal compaction range in which mechanical strength is maximized, while excessive increases in pressure do not generate significant benefits and can even affect the integrity of the material. Controlled curing methods, particularly wet curing and CO_2 carbonation, were also found to significantly improve the strength and durability of the blocks.

One of the main findings was the lack of standardization in manufacturing processes, which explains the high dispersion of results in the literature. In this context, it was concluded that the manufacture of blocks with recycled materials should be approached from a comprehensive approach, in which material selection, compaction and curing are jointly optimized.

Finally, a manufacturing taxonomy and an integrated conceptual model were proposed to understand the relationship between process variables and mechanical performance. This contribution contributes to the generation of more robust technical criteria and facilitates decision-making in the design and production of sustainable blocks.

BIBLIOGRAPHIC REFERENCES

1. 1st International Conference on Advances in Civil Infrastructure Engineering, ICACIE 2012. (2013). Advanced Materials Research, 639-640(1).
2. 3rd International Conference on Civil Engineering and Transportation, ICCET 2013. (2014). Applied Mechanics and Materials, 507.
3. Asif, U., & Javed, M. F. (2024). Optimizing plastic waste inclusion in paver blocks: Balancing performance, environmental impact, and cost through LCA and economic analysis. Journal of Cleaner Production, 478, 143901. doi: https://doi.org/10.1016/j.jclepro.2024.143901
4. Attia, M. I., Zoorob, S., Hassan, K., El-Husseini, H., Reid, J. M., & Al Kuwari, M. S. (2017). Development of building blocks using vegetable oil and recycled aggregate. Paper presented at the MATEC Web of Conferences.
5. Baur, E., Osswald, T. A., & Rudolph, N. (2019). 4 - Plastic Processing Technologies. In Plastics Handbook (pp. 177-336): Hanser.
6. Bouhiyadi, S., Souinida, L., & Hassouani, Y. E. L. (2025). Physicochemical and thermomechanical characterization of compressed earth blocks stabilized with cement or wood ash. Sustainable Cities and Society: Advances, 1(1), 100011. doi: https://doi.org/10.1016/j.scsadv.2025.100011
7. Courard, L., Grigoletto, S., Libert, R., Troquay, J., & Long, M. (2026). Rammed Concrete with Recycled Concrete Aggregates: Opportunities and Performances. Journal of Sustainability Research, 8(1). DOI:10.20900/JSR20260020
8. Deng, X., Li, J., Lu, Z., Li, X., Hou, L., Jiang, J., . . . He, K. (2024). Performance of Fully Recycled Aggregate Rockfill Concrete. Bulletin of the Chinese Ceramic Society, 43(8), 2996-3004.
9. Farooq, M. U., Hameed, R., Tahir, M., Sohail, M. G., & Shahzad, S. (2023). Mechanical and durability performance of 100% recycled aggregate concrete pavers made by compression casting. Journal of Building Engineering, 73, 106729. doi: https://doi.org/10.1016/j.jobe.2023.106729
10. Hossain, M. U., Wang, L., Chen, L., Tsang, D. C. W., Ng, S. T., Poon, C. S., & Mechtcherine, V. (2020). Evaluating the environmental impacts of stabilization and solidification technologies for managing hazardous wastes through life cycle assessment: A case study of Hong Kong. Environment International, 145, 106139. doi: https://doi.org/10.1016/j.envint.2020.106139
11. Hossain, M. U., Xuan, D., Ng, S. T., & Amor, B. (2021). Designing sustainable partition wall blocks using secondary materials: A life cycle assessment approach. Journal of Building Engineering, 43, 103035. doi: https://doi.org/10.1016/j.jobe.2021.103035
12. Jhon Castillo Marín, A., Yerson Tacilla Culqui, C., & Alva Sarmiento, A. (2024). Use of Recycled Coarse Aggregate in Concrete f'c=210 kg/cm2 when Incorporating Percentages of Recycled Coarse Aggregate. Paper presented at the Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology.
13. Juan-Valdés, A., Rodríguez-Robles, D., García-González, J., Guerra-Romero, M. I., & Morán-del Pozo,

J. M. (2018). Mechanical and microstructural characterization of non-structural precast concrete made with recycled mixed ceramic aggregates from construction and demolition wastes. Journal of Cleaner Production, 180, 482-493. doi: https://doi.org/10.1016/j.jclepro.2018.01.191

14. Junkes, V. H., Fuziki, M. E. K., Tusset, A. M., Rodrigues, P. H., & Lenzi, G. G. (2024). Environmentally friendly concrete block production: valorization of civil construction and chemical industry waste. Environmental Science and Pollution Research, 31(12), 17788-17803. DOI:10.1007/S11356-023-31706-Y
15. Kumar Chilukuri, S., Narendra Raut, A., Kumar, S., Singh, R. J., & Sakhare, V. (2023). Enhancing thermal performance and energy Efficiency: Optimal selection of steel slag crumb rubber blocks through Multi-Criteria decision Making. Construction and Building Materials, 409, 134094. doi: https://doi.org/10.1016/j.conbuildmat.2023.134094
16. Mastali, M., Abdollahnejad, Z., & Pacheco-Torgal, F. (2018). Performance of waste based alkaline mortars submitted to accelerated carbon dioxide curing. Resources, Conservation and Recycling, 129, 12-19. doi: 10.1016/j.resconrec.2017.10.017
17. Mastali, M., Abdollahnejad, Z., & Torgal, F. P. (2019). Mechanical strength and freeze-thaw resistance of fly ash alkaline-based mortars containing recycled aggregates summited to accelerated carbonation. Paper presented at the Advances in Engineering Materials, Structures and Systems: Innovations, Mechanics and Applications - Proceedings of the 7th International Conference on Structural Engineering, Mechanics and Computation, 2019.
18. Merino-Lechuga, A. M., Lamaa, G., Silva, R. V., de Brito, J., Jiménez, J. R., Fernández-Rodríguez, J. M., & González-Caro, Á. (2025). Technical and environmental assessment of CO2-cured alkali-activated pervious paving blocks incorporating recycled aggregates. Construction and Building Materials, 489, 142286. doi: https://doi.org/10.1016/j.conbuildmat.2025.142286
19. Muhit, I. B., Omairey, E. L., & Pashakolaie, V. G. (2024). A holistic sustainability overview of hemp as building and highway construction materials. Building and Environment, 256, 111470. doi: https://doi.org/10.1016/j.buildenv.2024.111470
20. Narayanaswamy, A. H., Walker, P., Venkatarama Reddy, B. V., Heath, A., & Maskell, D. (2020). Mechanical and thermal properties, and comparative life-cycle impacts, of stabilised earth building products. Construction and Building Materials, 243, 118096. doi: https://doi.org/10.1016/j.conbuildmat.2020.118096
21. Othman, N. S. B., Nor, N. M., Saliah, S. N. M., & Nujid, M. M. (2025). Strength Performance of Two-Hollow Interlocking Concrete Block Inclusion with Recycled Concrete Aggregate as A Replacement of Natural Fine Aggregate. Jurnal Kejuruteraan, 37(3), 1099-1116. DOI:10.17576/JKUKM-2025-37(3)-03
22. Roknuzzaman, M., & Rahman, M. M. (2024). Compressive Strength of Recycled Green Concrete Affected by Chloride and Sulfate Exposures. Journal of Rehabilitation in Civil Engineering, 12(4), 55-65. doi:10.22075/JRCE.2024.32378.1938
23. Roknuzzaman, M., Rahman, M. M., & Islam, M. M. (2025). Performance and Usability Assessment of Recycled Aggregate Extracted from Demolished Concrete Subjected to Multiple Recycling. Journal of Rehabilitation in Civil Engineering, 13(4), 161-176. DOI:10.22075/JRCE.2025.35008.2158
24. Sabai, M. M., Cox, M. G. D. M., Mato, R. R., Egmond, E. L. C., & Lichtenberg, J. J. N. (2013). Concrete block production from construction and demolition waste in Tanzania. Resources, Conservation and Recycling, 72, 9-19. doi:10.1016/j.resconrec.2012.12.003
25. Saeli, M., Batra, V. S., Singh, R. K., Tobaldi, D. M., & Labrincha, J. A. (2023). The coffee-house: Upcycling spent coffee grounds for the production of green geopolymeric architectural energy-saving products. Energy and Buildings, 286, 112956. doi: https://doi.org/10.1016/j.enbuild.2023.112956
26. Shareef, Z. A., Ahmed, S. Y., & Abdulkareem, O. M. (2023). Potential Use of Wastes of Thermostone Blocks and Ceramic Tiles as Recycled Aggregates in Production of Foam Concrete. Civil Engineering and Architecture, 11(3), 1280-1296. doi:10.13189/cea.2023.110314
27. Soutsos, M. N., Tang, K., & Millard, S. G. (2011). Concrete building blocks made with recycled demolition aggregate. Construction and Building Materials, 25(2), 726-735. doi: 10.1016/j.conbuildmat.2010.07.014
28. Supriya, C. B., Manjunath, B. H., Prakash, J., & Sahana, T. S. (2024). Fly Ash-Based RAGPC Paver Blocks for Moderate Traffic Volume Roads. Paper presented at the Lecture Notes in Civil Engineering.
29. Turgut, P. (2013). Fly ash block containing limestone and glass powder wastes. KSCE Journal of Civil Engineering, 17(6), 1425-1431. doi: https://doi.org/10.1007/s12205-013-0280-6

30. Valenzuela, M., Ciudad, G., Cárdenas, J. P., Medina, C., Salas, A., Oñate, A., . . . Tuninetti, V. (2024). Towards the development of performance-efficient compressed earth blocks from industrial and agro-industrial by-products. Renewable and Sustainable Energy Reviews, 194, 114323. doi: https://doi.org/10.1016/j.rser.2024.114323
31. Zhan, B., Poon, C., & Shi, C. (2013). CO2 curing for improving the properties of concrete blocks containing recycled aggregates. Cement and Concrete Composites, 42, 1-8. doi: 10.1016/j.cemconcomp.2013.04.013
32. Zhan, B. J., Poon, C. S., & Shi, C. J. (2016). Materials characteristics affecting CO2 curing of concrete blocks containing recycled aggregates. Cement and Concrete Composites, 67, 50-59. doi: 10.1016/j.cemconcomp.2015.12.003
33. Zhan, B. J., Xuan, D. X., Poon, C. S., & Shi, C. J. (2016). Effect of curing parameters on CO2 curing of concrete blocks containing recycled aggregates. Cement and Concrete Composites, 71, 122-130. doi: 10.1016/j.cemconcomp.2016.05.002
34. Zhou, Z., He, Q., Xiao, Y., Dong, N., Cao, J., Yang, T., & Sun, X. (2025). On shear strength and microstructure characteristics of dredged sludge treated synergistically by aggregates recycled from building, demolition, waste, blast, furnace, powder, and cement. Journal of Railway Science and Engineering, 22(2), 677-689. DOI:10.19713/J.CNKI.43-1423/U.T20240620
35. Zhuge, Y., Duan, W., & Liu, Y. (2022). 9 - Utilization of wood waste ash in green concrete production. In R. Siddique & R. Belarbi (Eds.), Sustainable Concrete Made with Ashes and Dust from Different Sources (pp. 419-450): Woodhead Publishing.