

Comparative Study of the Mechanical and Durability Performance of Interlocking Concrete Pavement Blocks

Ravi Raushan^{1*}, Prateek Sharma²

Abstract

Interlocking concrete pavement blocks (ICPBs) have emerged as a durable, modular, and sustainable alternative to traditional pavement systems. Their performance depends heavily on the mechanical characteristics of the concrete mix, block geometry, compaction technique, and curing conditions. This review compiles and analyzes research findings related to the strength, durability, structural behavior, and long-term performance of ICPBs produced using traditional and modified concrete mixes. Key parameters evaluated include compressive strength, split tensile strength, abrasion resistance, water absorption, flexural performance, and interlocking efficiency. The review also includes comparative tables, graphs, and insights into the influence of supplementary cementitious materials (SCMs), recycled aggregates, and surface treatments on pavement block performance. Findings reveal that optimized mix design and proper manufacturing techniques significantly enhance the mechanical and durability properties of ICPBs, enabling their use in heavy-duty applications and sustainable urban infrastructure.

Keywords: Interlocking concrete blocks, paver blocks, durability, mechanical performance, pavement engineering

INTRODUCTION

Interlocking concrete pavement blocks (ICPBs) have gained widespread use in urban infrastructure owing to their ease of installation, high load distribution efficiency, modularity, and maintenance benefits. Unlike continuous pavements, ICPBs rely on a combination of block geometry, joint sand, and edge restraints to form a stable structural layer that can resist traffic loads [1–3].

Conventional concrete pavements rely on Portland cement and natural aggregates, which raise sustainability concerns owing to high CO₂ emissions and excessive quarrying. Consequently, recent studies have investigated the potential of alternative materials, such as recycled concrete aggregates (RCA), ceramic waste, fly ash, GGBS, and other industrial by-products, for ICPB production.

*Author for Correspondence

Ravi Raushan
Email: 2023pceceravi803@poornima.org

¹Student, Department of Civil Engineering, Poornima College of Engineering, Jaipur, Rajasthan, India

²Assistant Professor, Department of Civil Engineering, Poornima College of Engineering Jaipur, Rajasthan, India

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The ICPB performance was evaluated based on mechanical strength, abrasion resistance, permeability, and long-term durability under traffic and environmental stress. This review systematically analyzes these factors and provides detailed comparative data extracted from the literature (Figure 1) [4–6].

METHODOLOGY: STRUCTURE OF THE REVIEW

A systematic review method was adopted using the keywords “interlocking concrete block pavements,” “mechanical strength of paver

blocks,” “durability performance,” “RCA paver blocks,” and “SCM-modified paver blocks.”

Sources included Scopus, Web of Science, ASCE, Elsevier, and peer-reviewed journals published between 2008 and 2024.

The review was structured to evaluate the mechanical strength properties of ICPBs.

- Analyze microstructural factors (porosity, interfacial transition zone (ITZ) quality, aggregate interlock).
- Summarize treatment and optimization techniques.
- Durability parameters, including abrasion, permeability, freeze–thaw, and chemical resistance, were examined.
- Assess sustainability benefits, cost efficiency, and practical implementation (Figure 2).

LITERATURE REVIEW AND PERFORMANCE CHARACTERISTICS

Research on ICPBs has primarily focused on load-bearing capacity, interlocking efficiency, durability, material optimization, and structural performance under repetitive loads.

Mechanical Strength

Mechanical strength includes compressive, flexural, and split tensile strength.

Compressive Strength

- Standard paver blocks require 30–50 MPa depending on grade.
- The strength is influenced by the water–cement ratio, compaction pressure, curing, and aggregate type, as shown in Figure 3.

Tensile and Flexural Strength

Similar patterns were observed for the tensile and flexural strengths. The presence of ceramic waste enhances crack resistance owing to its angular particles that provide mechanical interlocking, whereas RCA increases the strain capacity by introducing microvoids that delay crack propagation [3, 7]. These properties slightly reduce the ultimate strength but improve the ductility, impact absorption, and failure warning behavior compared with conventional concrete, as shown in Figure 4.

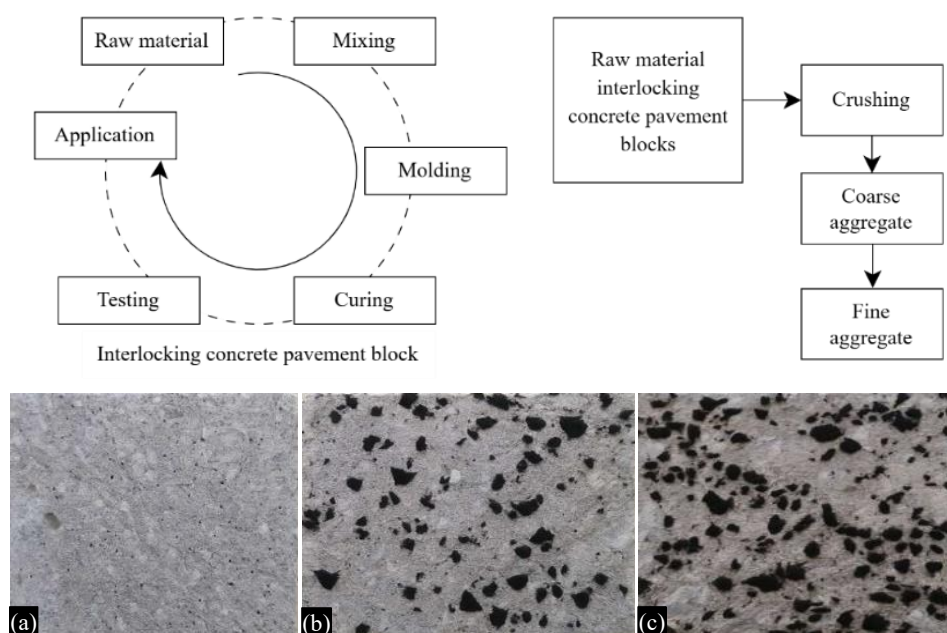


Figure 1. (a)–(c) Interlocking concrete pavement blocks.

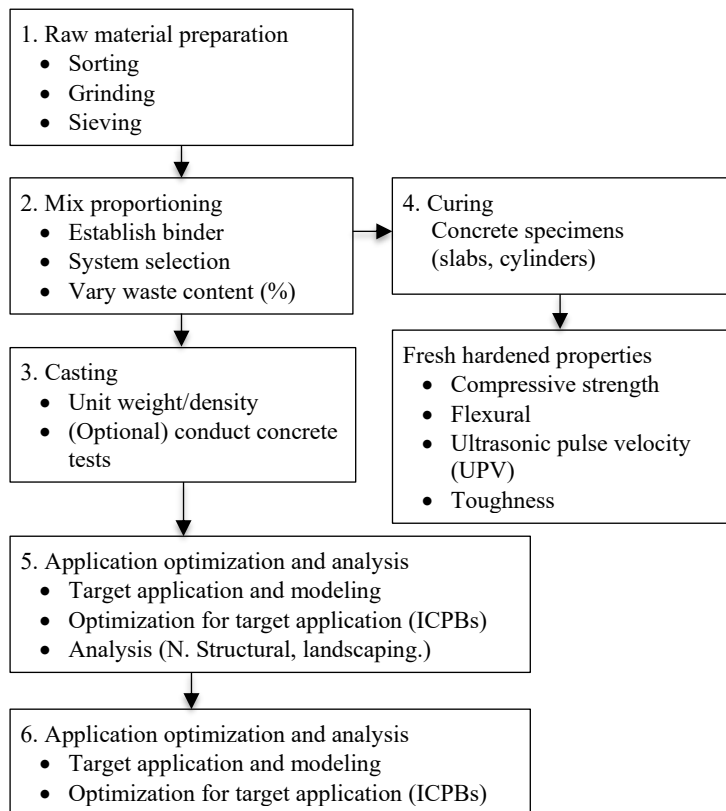


Figure 2. Interlocking concrete pavement block.

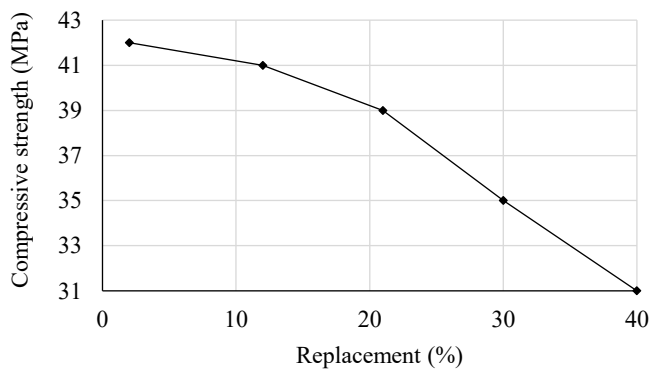


Figure 3. Compressive strength versus water replacement.

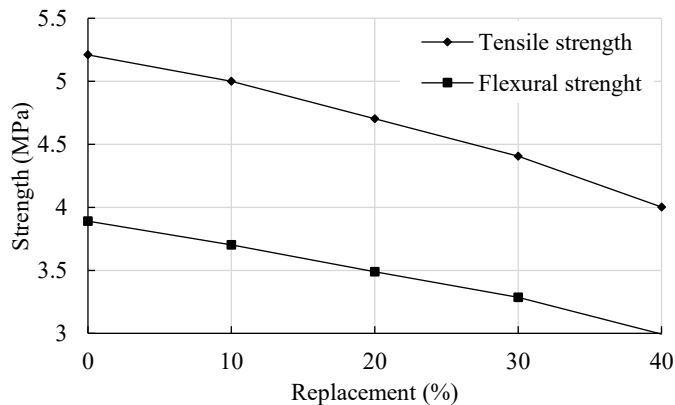


Figure 4. Tensile and flexural strength.

Stress–Strain Behavior and Density

Concrete with RCA generally exhibits a more gradual stress–strain curve and less brittle failure behavior. The lower density of waste aggregates (due to residual mortar and internal pores) reduces the unit weight by 5–12%, making it advantageous for lightweight structural or non-load-bearing applications [5, 6].

Mechanisms of Strength Reduction

The variation in the mechanical performance is primarily influenced by three microstructural mechanisms [6, 7]:

- *High porosity and absorption:* Recycled concrete and ceramic particles contain old mortar and microcracks that absorb additional water, affecting workability and interfacial bonding.
- *Weak interfacial transition zone:* The bond between the old mortar or ceramic surface and the new paste is weaker owing to residual cement dust and a lack of chemical reactivity. This region served as the primary path for microcrack propagation.
- *Increased voids and microcracks:* Crushing and handling of waste aggregates often introduce fine cracks and entrapped air pockets, which lower the compressive strength but increase the energy absorption and damping ability.

The Interfacial Transition Zone Optimization and Treatment Methods

Improving the ITZ quality between waste particles and new cement paste is essential for ensuring strength recovery. Typical improvement strategies include the following:

- *Surface cleaning and soaking:* Pre-soaking RCA or ceramic aggregates in water reduces their absorption capacity and helps achieve more consistent water–cement ratios during mixing.
- *Chemical treatment:* Washing aggregates with mild acids or applying silica-based solutions enhances surface reactivity, leading to stronger interfacial bonding [7].
- *Use of supplementary cementitious materials (SCMs):* Additives such as fly ash, silica fume, or ground granulated blast furnace slag (GGBFS) fill the pores around the waste particles, densifying the ITZ and improving the long-term strength.
- *Hybrid blending:* Combining ceramic and RCA in optimized proportions provides a balanced performance; ceramic fines improve matrix compactness, whereas RCA contributes to reduced density and enhanced sustainability.

Durability and Resilience: The Key Advantages

Although some mechanical properties may decline, durability and resilience often improve with waste incorporation [5, 8]. Ceramic particles are inherently chemically inert and thermally stable, whereas RCA's porous microstructure of RCA promotes better stress dissipation, as shown in Figure 5.

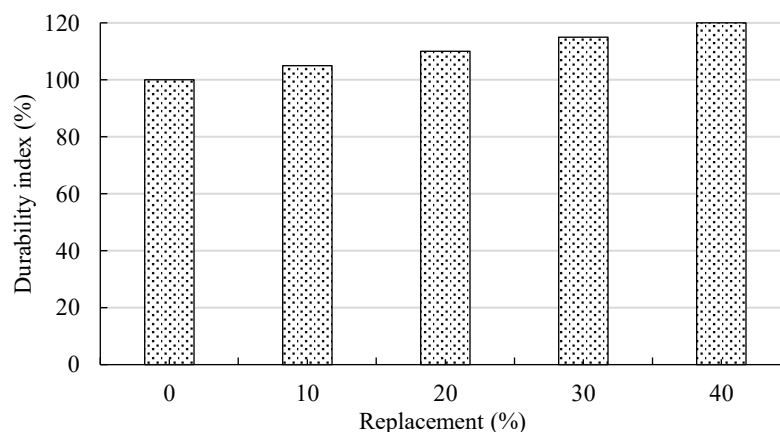


Figure 5. Durability index improvement with waste replacement.

Table 1. Summary of interlocking block performance studies.

S.N.	Author and year	Mix type/variable studied	compressive strength findings	Flexural/tensile strength findings	Durability findings
1	Tergou et al. 2019	RCA as coarse aggregate (10–50%)	Strength reduction beyond 30%	Slight decrease	improved freeze–thaw behavior
2	Sharma and Kumar, 2021	Fly ash replacement (10–25%)	Strength comparable to 20%)	improved flexural strength	Reduced permeability
3	Da Silva et al., 2018	GGBS-modified pavers	Increased compressive strength	Higher tensile resistance	Superior sulfate resistance
4	Li and Xu, 2020	Fiber-reinforced ICPBs	Improved load bearing	higher impact resistance	excellent abrasion resistance
5	Patel et al., 2022	Ceramic waste as fine aggregate	slight strength loss	Better crack control	improved thermal resistance
6	Khalid et al., 2023	Hybrid RCA + SCM blends	recovered strength	comparable tensile	better chemical durability

- *Water and chloride permeability:* Properly designed mixes using fine ceramic powder exhibited lower permeability owing to pore refinement and reduced capillary channels.
- *Freeze–thaw resistance:* The porous RCA structure allows internal accommodation of expansion pressures, thereby reducing cracking during cyclic freeze–thaw.
- *Thermal and fire resistance:* Ceramic aggregates enhance heat resistance, preventing explosive spalling, and improving residual strength after exposure to high temperatures.
- *Impact and abrasion resistance:* Waste-based concrete exhibits superior energy absorption and toughness owing to improved crack-bridging mechanisms and a heterogeneous structure, as shown in Table 1 [9–12].

INNOVATIVE APPLICATIONS AND SUSTAINABILITY

Specialized Applications for Ceramic and RCA Concrete

The combination of ceramic waste and RCA enhances sustainability while maintaining sufficient structural performance. These materials are particularly beneficial in nonstructural and semistructural applications, where durability and environmental impact are priorities.

- *Pavements and sidewalks:* The lower density and enhanced abrasion resistance of ceramic waste concrete make it ideal for pavements, curbs, and footpaths [13–15].
- *Precast and Block Elements:* Their moderate strength and high dimensional stability are suitable for masonry blocks, tiles, and non-load-bearing walls.
- *Thermal and Acoustic Panels:* Ceramic-based composites have low thermal conductivity and good sound insulation properties, making them suitable for interior wall panels.
- *Road sub-base and structural fill:* RCA provides excellent compaction and drainage, reducing the natural aggregate demand for base layers in road construction.
- *Architectural and eco-friendly concrete:* The use of red ceramic waste adds aesthetic value with natural pigmentation and improved heat reflectivity.

Environmental and Economic Sustainability

Ceramic and RCA concrete directly support circular economy principles by transforming construction waste into functional building materials.

- *Waste management:* Reusing ceramic tiles and demolished concrete significantly reduces landfill accumulation and the demand for virgin aggregates.
- *Resource conservation:* Replacing 20–30% of natural coarse aggregates with RCA can lower natural resource extraction by up to 25%, thereby extending quarry life.
- *Life cycle assessment (LCA):* Studies have shown that incorporating recycled materials reduces the embodied carbon footprint by 15–40%, mainly through decreased energy consumption and waste transport.

- *Thermal efficiency:* Ceramic materials exhibit low thermal conductivity, improving the insulation performance of concrete elements and thereby reducing the operational energy in buildings.
- *Economic viability:* Although additional crushing and cleaning steps slightly increase processing costs, the savings in raw material procurement, landfill disposal fees, and environmental levies result in a net economic benefit.

In summary, integrating ceramic and RCA waste offers a dual benefit: minimizing environmental burden and creating cost-effective, durable, and thermally efficient construction materials [15, 16].

FUTURE SCOPE

The widespread adoption of ceramic and RCA-based concrete depends on ongoing improvements in processing, testing, and regulations. Future research directions can be summarized as follows:

Improved Material Processing and Surface Treatment

- *New conditioning techniques:* Studies should focus on sustainable cleaning and activation methods, such as carbonation, ultrasonic cleaning, and plasma treatment, to enhance surface reactivity without generating chemical waste.
- *Optimization of particle size and grading:* Establishing standardized ranges for particle gradation (fine and coarse) to achieve uniform strength and durability performance.

Structural and Code Implementation

- *Expansion to load-bearing components:* Further large-scale structural testing is required to validate the use of beams, columns, and slabs.
- *Standardization and guidelines:* Development of design codes and acceptance criteria to facilitate the safe use of RCA and ceramic-based materials in mainstream construction.

Hybrid and Multifunctional Composites

- *Blending with SCMs and other wastes:* Combining ceramic waste and RCA with fly ash, slag, or glass powder can enhance strength recovery and durability through synergistic pozzolanic reactions.
- *Functional integration:* Future studies can explore multifunctional concrete with self-healing, heat resistance, and electromagnetic shielding capabilities.

Long-Term Durability and Environmental Assessments

- *Field validation:* Extended field trials under different climatic and loading conditions to assess freeze-thaw, carbonation, and fatigue performances.
- *Leaching and environmental safety:* Long-term studies on potential leachate and microparticle release from RCA to ensure compliance with environmental regulations.

CONCLUSION

Incorporating ceramic and recycled concrete waste into construction materials provides a highly effective and sustainable approach to address both environmental and resource-related challenges in the construction sector. Although the inclusion of these waste materials may result in moderate reductions in compressive and tensile strengths at higher replacement levels, these effects can be mitigated through optimized mix designs, suitable particle grading, and the addition of SCMs, such as fly ash or silica fume. The resulting composites demonstrated improved durability, thermal resistance, and long-term performance owing to their refined microstructure and enhanced ITZ.

Moreover, reusing ceramic and concrete waste significantly reduces landfill disposal, curbs the extraction of natural aggregates, and lowers the carbon footprint of concrete production. These sustainability benefits directly support circular economy principles and contribute to the global goals

of reducing construction waste and CO₂ emissions. Therefore, concrete made with ceramic and recycled aggregates is a technically viable and environmentally responsible material for future sustainable infrastructure, enabling a balance between performance, cost efficiency, and ecological impact.

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