



A Comprehensive Review on Reclaimed Asphalt Pavement and Rice Husk Ash in Pervious Concrete

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ABSTRACT

Pervious concrete has emerged as a sustainable pavement material due to its ability to facilitate rapid stormwater infiltration, mitigate surface runoff, and promote groundwater recharge. However, its broader application is constrained by inherently low mechanical strength and the environmental burden associated with the extensive use of natural aggregates and Portland cement. To address these challenges, the incorporation of Reclaimed Asphalt Pavement (RAP) and Rice Husk Ash (RHA) has emerged as a resource-efficient and sustainable alternative. RAP, derived from recycled asphalt layers, enhances porosity and hydraulic conductivity through increased void connectivity; however, it compromises mechanical performance due to aged bitumen coatings, adhered fines, and the formation of weak interfacial transition zones (ITZ). In contrast, RHA, a silica-rich agricultural by-product, exhibits high pozzolanic reactivity, promoting the formation of additional calcium silicate hydrate (C-S-H) gel, which improves matrix densification, interfacial bonding, and long-term strength development. These competing mechanisms define the critical balance between permeability and mechanical integrity in RAP-RHA-modified pervious concrete systems. This review presents a critical synthesis of the physical, mechanical, hydraulic, and durability performance of pervious concrete incorporating RAP and RHA, with particular emphasis on pore structure evolution and ITZ behavior. Despite extensive research on their individual utilization, a mechanistic understanding of their coupled interaction—specifically the interplay between RAP-induced void architecture and RHA-driven pozzolanic densification—remains underdeveloped. Accordingly, this study identifies key research gaps and establishes a mechanistically grounded framework for optimizing RAP-RHA blended systems. By explicitly linking microstructural evolution to macro-scale performance, the study provides a pathway for designing high-performance, sustainable pervious concrete with an optimized strength-permeability balance, advancing the development of resilient and environmentally responsive pavement infrastructure.

Keywords: Pervious concrete, Reclaimed Asphalt Pavement, Rice Husk Ash, Interfacial Transition Zone, Pore structure, Permeability, Mechanical performance, Sustainable pavement.

1. Introduction

In recent years, pervious concrete has emerged as a promising sustainable solution in civil engineering to address critical challenges related to stormwater management, environmental degradation, and resource depletion. Characterized by a highly interconnected void structure, pervious concrete also referred to as porous concrete, permeable concrete, or no-fines concrete facilitates rapid water infiltration through its matrix, enabling direct percolation into the subgrade [1,2]. This unique functionality significantly reduces surface runoff, mitigates urban flooding, and promotes groundwater recharge. Due to these advantages, pervious concrete is widely applied in flatwork applications such as parking areas, pedestrian pathways, and low-volume pavements [3]. The infiltration mechanism through its interconnected pore network is illustrated in Figure 1.

The increasing demand for sustainable infrastructure systems, coupled with the adverse impacts of impermeable surfaces and climate variability, has accelerated the global adoption of pervious concrete pavement systems [4]. Unlike conventional dense concrete, pervious concrete is specifically designed for permeability rather than structural load-bearing applications. Its mechanical and hydraulic performance is

governed by key parameters such as aggregate gradation, particle shape, cementitious content, and water-cement ratio [5]. While the high porosity of pervious concrete enhances permeability, it simultaneously leads to reduced mechanical strength, thereby limiting its broader structural application[6].



Figure 1: Visualization of water infiltration through the interconnected void structure of pervious concrete, illustrating permeability pathways and aggregate skeleton.

To address these limitations and enhance sustainability, the incorporation of recycled and waste-derived materials has gained considerable attention. Among these, Reclaimed Asphalt Pavement (RAP) has emerged as a viable alternative to natural aggregates. RAP is obtained from recycled asphalt materials, including reclaimed road surfaces and asphalt shingles, and its incorporation in pervious concrete contributes to both environmental and economic benefits[7]. Specifically, RAP utilization aids in reducing landfill disposal of asphalt waste and minimizes the demand for virgin aggregates, thereby lowering the overall ecological footprint of pavement construction[8].

However, the inclusion of RAP introduces complex microstructural interactions within the concrete matrix. The presence of aged bitumen coatings and adhered fines on RAP aggregates leads to the formation of weak interfacial transition zones (ITZ), which adversely affect bonding characteristics and mechanical performance. At the same time, RAP enhances void connectivity, thereby increasing permeability. This inherent trade-off between strength and permeability necessitates optimized material design strategies[7,8]. In parallel, Rice Husk Ash (RHA), an abundant agricultural by-product, has been extensively investigated as a supplementary cementitious material. Rich in amorphous silica, RHA exhibits significant pozzolanic activity, reacting with calcium hydroxide to form additional calcium silicate hydrate (C-S-H) gel. This reaction contributes to matrix densification, improved interfacial bonding, and enhanced long-term strength and durability [9]. Furthermore, the use of RHA reduces the reliance on Portland cement, thereby lowering carbon emissions and supporting sustainable construction practices[10].

Although previous studies have explored the individual effects of RAP and RHA in pervious concrete, their combined interaction-particularly in terms of pore structure evolution, ITZ behavior, and performance optimization-remains insufficiently understood. Therefore, this study presents a comprehensive review of the properties and performance of pervious concrete incorporating RAP and RHA. The review aims to critically evaluate their influence on mechanical, hydraulic, and durability characteristics while identifying key research gaps and future directions for developing high-performance, sustainable pavement systems. The overall framework of the review is illustrated in Figure 2.

2. Overview of RAP with its Properties

RAP is a recycled construction material composed of mineral aggregates coated with aged asphalt binder, generated during the milling or rehabilitation of existing asphalt pavements [11,12]. Due to its composite nature and residual bituminous coating, RAP exhibits distinct physical, mechanical, and hydraulic characteristics that differentiate it from conventional aggregates. These properties-including gradation, density, moisture content, shear strength, and hydraulic conductivity-play a critical role in determining its suitability for incorporation in pervious concrete systems [13].

Among these, gradation is a fundamental parameter governing particle packing, void distribution, and overall pore structure. It is typically characterized by particle size distribution parameters such as D_{10} , D_{30} , and D_{60} , along with the coefficients of uniformity (C_u) and curvature (C_c). Previous studies have demonstrated that variations in aggregate type and grading curve significantly influence mix design performance, particularly in terms of density and permeability [14]. The presence of aged bitumen coating on RAP aggregates alters the effective gradation, often resulting in a coarser particle distribution and reduced fines content, as illustrated in Figure 3. This shift in gradation enhances void connectivity but may compromise particle interlocking[15].

Moisture content further influences RAP behavior by affecting compaction efficiency and interfacial bonding. In asphalt-based systems, RAP-containing mixtures have demonstrated improved resistance to moisture-induced damage under controlled conditions [16]. However, in cementitious environments, excess moisture may weaken the bond between RAP aggregates and the cement matrix, thereby affecting mechanical performance.

Shear strength is another critical property governing the structural stability of RAP-based systems. Experimental investigations, including double-punch shear tests, indicate that RAP incorporation can result in comparable or marginally improved shear strength under specific conditions [17]. The mechanical response of RAP is highly dependent on temperature, binder condition, and aggregate interaction, with studies showing that RAP mixtures exhibit similar shear behavior to control specimens at lower temperatures [18]. Additionally, in reinforced systems, RAP has been shown to influence shear performance under varying thermal conditions, with design codes such as ACI and Eurocode generally providing conservative estimates [19].

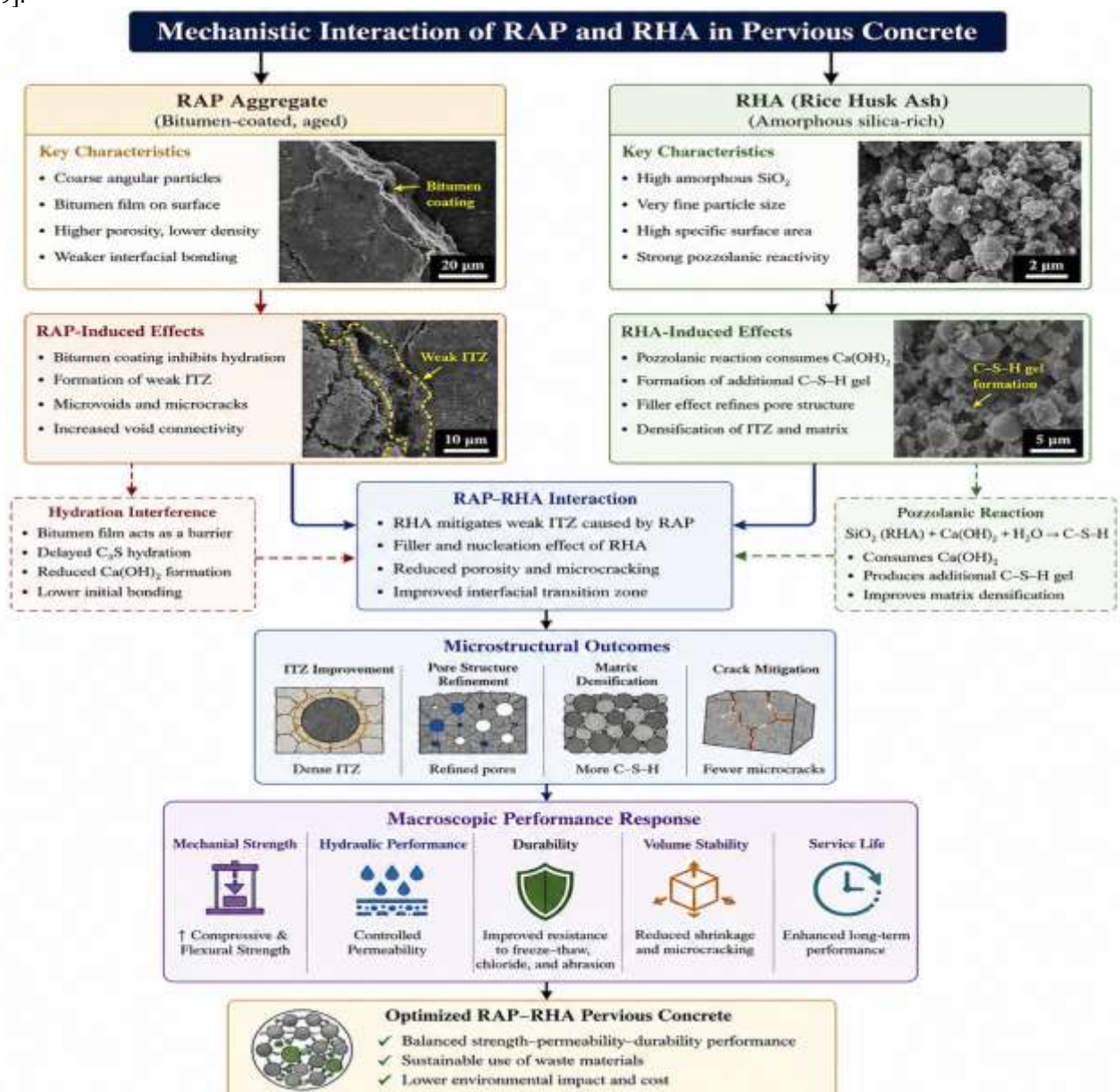


Figure 2: Outline of research review of the RAP and RHA in the pervious concrete

Hydraulic conductivity is particularly significant in the context of pervious concrete. The permeability of RAP is highly sensitive to fines content and compaction effort. Experimental studies have demonstrated that increasing fines content can reduce hydraulic conductivity by more than an order of magnitude under controlled conditions [20]. This highlights the importance of gradation control in maintaining permeability while ensuring adequate structural performance.

From a mechanistic perspective, the performance of RAP in pervious concrete is governed by competing

effects. The irregular geometry and surface roughness of RAP aggregates promote the formation of interconnected void networks, enhancing permeability. However, the presence of aged bitumen coatings and adhered dust particles leads to the development of weak and heterogeneous interfacial transition zones, resulting in reduced bonding strength and increased susceptibility to failure. These competing mechanisms underscore the necessity for optimized mix design strategies to balance permeability and mechanical performance in RAP-based pervious concrete systems.



Figure 3: Schematic image of original RAP materials collection and processing Sequence

3. Overview Of RHA with its Properties

Rice Husk Ash (RHA) has emerged as an effective supplementary cementitious material due to its ability to enhance the mechanical and durability performance of concrete when used as a partial replacement for Portland cement [21,22]. Previous studies indicate that the incorporation of RHA in the range of 5-10% by weight of cement can improve compressive strength without significantly compromising workability, although higher replacement levels may lead to reduced flowability due to the high specific surface area of RHA particles [23,24]. The performance of RHA-modified concrete is primarily governed by its chemical composition, pozzolanic reactivity, influence on durability, and environmental benefits [25].

Chemical Composition: RHA is predominantly composed of silica (SiO_2), typically ranging between 80% and 95%, depending on combustion temperature, burning conditions, and post-processing treatments. The silica in RHA is largely present in amorphous form, which is essential for its reactivity. X-ray fluorescence (XRF) analysis has shown that increasing RHA replacement levels leads to a corresponding increase in silica content in blended cement systems, for instance, from 23.40% at 5% replacement to 32.87% at 25% replacement [26]. Variations in silica content have also been reported depending on the source and processing of rice husk, highlighting the importance of controlled production conditions [27].

Pozzolanic Activity: The pozzolanic behavior of RHA is attributed to its high amorphous silica content, which reacts with calcium hydroxide (Ca(OH)_2) released during cement hydration to form additional calcium silicate hydrate (C-S-H) gel. This secondary hydration process contributes to long-term strength development and microstructural refinement. However, the reaction kinetics of RHA are generally slower compared to conventional pozzolanic materials, influencing setting time and early-age performance [28]. The effectiveness of this reaction depends on particle fineness, silica content, and curing conditions.

Durability Enhancement: The formation of additional C-S-H gel through pozzolanic reactions leads to pore refinement and densification of the cement matrix, thereby reducing permeability and improving resistance to the ingress of aggressive agents such as chlorides and sulphates. This results in enhanced durability performance, particularly in terms of resistance to chemical attack and long-term degradation. Studies have demonstrated that RHA can serve as a cost-effective alternative to high-performance materials such as silica

fume while maintaining comparable durability characteristics [29].

Environmental Benefits: From a sustainability perspective, RHA offers significant environmental advantages by reducing dependence on Portland cement, which is a major contributor to global CO₂ emissions. The utilization of RHA, an agricultural waste product, not only promotes waste valorization but also lowers the overall carbon footprint of concrete production. Life-cycle assessment studies have shown that concrete mixes incorporating RHA, particularly in combination with other supplementary cementitious materials, exhibit reduced global warming potential (GWP) while maintaining or improving durability performance [30].

4. Incorporating RAP And RHA in the Pervious Concrete

RAP is a recycled material derived from the milling and rehabilitation of existing asphalt pavements and has gained significant attention as a sustainable alternative to natural aggregates in pervious concrete systems. The incorporation of RAP contributes to resource conservation by reducing the reliance on virgin aggregates and minimizing the environmental burden associated with quarrying activities [31,32]. In addition to environmental benefits, RAP utilization offers economic advantages by lowering material procurement costs and reducing expenses related to the disposal of asphalt waste, thereby enhancing the overall cost efficiency of pavement construction [33]. However, the presence of aged bitumen coating on RAP aggregates introduces challenges related to interfacial bonding and mechanical performance, which must be carefully addressed during mix design.

Rice Husk Ash (RHA), on the other hand, functions as a highly reactive supplementary cementitious material due to its rich amorphous silica content. Through pozzolanic reactions, RHA interacts with calcium hydroxide (Ca(OH)₂) released during cement hydration to form additional calcium silicate hydrate (C-S-H) gel, thereby improving matrix densification and enhancing long-term strength and durability [34,35]. The incorporation of RHA also contributes to sustainability by partially replacing Portland cement, leading to a reduction in carbon emissions associated with cement production [36]. Furthermore, the fine particle size and high specific surface area of RHA provide a filler effect, refining the pore structure and improving the interfacial transition zone (ITZ) within the concrete matrix.

The combined incorporation of RAP and RHA in pervious concrete introduces a complex interaction between aggregate characteristics and binder chemistry. While RAP tends to increase void connectivity and permeability due to its irregular geometry and reduced density, it simultaneously weakens interfacial bonding because of the bitumen layer. Conversely, RHA enhances matrix cohesion and ITZ quality through pozzolanic densification and pore refinement. This complementary behavior suggests the potential for achieving an optimized balance between mechanical strength and hydraulic performance when both materials are used synergistically.

The performance of RAP-RHA-modified pervious concrete is highly dependent on mix design parameters, including aggregate content, cementitious composition, water-cementitious material ratio, and the use of chemical admixtures. Proper proportioning is essential to control porosity, maintain adequate workability, and ensure structural integrity. Variations in RAP replacement levels and RHA content significantly influence the strength-permeability relationship, highlighting the need for optimized mix formulations.

Table 1 summarizes the findings of previous studies on the incorporation of RAP and RHA in pervious concrete, including their objectives, mix proportions, key outcomes, and identified limitations. These studies collectively demonstrate the potential of RAP and RHA as sustainable materials while also emphasizing the need for further research to fully understand their combined effects on microstructural behavior and long-term performance.

The influence of Reclaimed Asphalt Pavement (RAP) on concrete performance has been widely investigated in both conventional and pervious concrete systems. Munagala et al. [42] examined the use of RAP in pavement quality cement concrete by replacing both fine and coarse aggregates at levels of 0%, 15%, 30%, 45%, and 60%. The experimental results, supported by numerical validation, indicated that increasing RAP content led to a reduction in overall concrete performance, primarily due to weaker interfacial bonding and the presence of aged bitumen.

In the context of pervious concrete, Mohammed et al. [43] evaluated the performance of mixes incorporating 100% undiluted and diluted RAP materials. Five distinct mixes were developed, including a control mix (N), epoxy-treated RAP (ER), diluted epoxy RAP (DER), and corresponding mixes with 5% silica fume (ER+S and DER+S). The results demonstrated that mixes containing epoxy-treated RAP exhibited significantly improved permeability compared to the control mix. However, the incorporation of silica fume reduced permeability due to pore refinement and densification of the matrix, highlighting the trade-off between hydraulic performance and strength enhancement.

Similarly, Surya et al. [44] investigated the use of RAP as a replacement for natural coarse aggregates in pervious concrete pavement (PCP) mixes at replacement levels of 0%, 25%, 50%, 75%, and 100%. The findings revealed that increasing RAP content enhanced the permeability coefficient, indicating improved water percolation due to increased void connectivity.

Table 1: Research studies associated with adding RAP and RHA in the pervious concrete with its

objective, mixing proportions, findings, and limitations

Author name	Objective	Mixing considerations	Findings	Limitations
Thevaneyan, et al. [37]	Analyze the performance of surface infiltration rate of pervious concrete containing waste tire rubber and RAP with pervious concrete	M1 - Control Sample; M2 - RAP & 0% Fine Crumb Rubber (FCR), M3 - RAP w/ 5% FCR and M4 - RAP w/ 15% FCR	Surface infiltration rate	Codes and standards impose restrictions on the use of RAP in concrete. These limitations ensure that the structural integrity and performance of concrete were not compromised.
			M4 - RAP w/ 15% FCR indicated a better surface infiltration rate when compared with other mixes	
Siddharth, et al. [38]	To utilize the RHA materials to develop a pervious concrete mixture proportion	R Mix1, R Mix2, R Mix3, R Mix4, R Mix5 and R Mix6: 0, 10 and 20% of RHA	Strength	It will be more challenging to handle and place the concrete due to increased stiffness.
			Strength attained up to 10% replacement of cement with RHA will be optimum without affecting properties of hardened concrete	
Nikhil, et al. [39]	To assess the performance of pervious paver blocks by utilizing the RAP	RAP aggregates, Virgin aggregates (VA), and RAP were mixed in 3 proportions, such as 0–100, 50–50, and 100–0 using different aggregate gradations	Sustainability aspect	PPB with RAP aggregates experienced durability challenges.
			As 50% RAP was used in the pervious concrete paver block, the performance of G1 gradation was enhanced based on the aspect of sustainability.	
Shafabakhsh, et al. [40]	To examine the effects of coal waste ash (CWA) and rice husk ash (RHA)	A and B mix design with 5, 10, 15, and 20 % of CWA and 2, 4, 6, 8, 10 and 12 % RHA	Permeability	The effectiveness of RHA varies significantly, and the optimum percentage for enhancing properties may not be consistent.
			The amount of RHA in the pervious concrete was increased and its permeability was decreased.	
Abhyanshu, et al. [41]	To develop the pervious paver blocks using RAP	RAP mixing weight ratios of 0%, 50%, and 100%.	Porosity	The quality of the mixture or the pore design was affected because of the infiltration rate.
			The porosity of G2-graded mixtures was better when compared with G1-graded mixtures.	

Table 2: Research studies of mechanical performance of RAP and RHA in the pervious concrete with

its findings and limitations

Author name	Mechanical properties	Mixing considerations	Findings	Limitations
Susana, et al. [53]	Compressive strength and flexural strength	10% RAP, 20% RAP, 50% RAP, and 100% RAP	Flexural strength: 14.2 %, 7.1 %, 16.9 %, and 46.4 %; Compressive strength (28 days): 18 %, 14 %, 49 %, and 71 %	Clogging of the pore system of the pervious concrete was limited.
Saeid, et al. [54]	Permeability, compressive strength, and flexural strength	Mix 1 (Series A), Mix 2 (Series 2), Mix 3 (Series 3), and Mix 4 (Series 4)	Pervious concrete permeability: 0.08 cm/s and 0.48 cm/s; Compressive strength of pervious concrete: RHA increases by 34%, 37%, and 36% for glass, steel, and PPS fibers, and flexural strength: 64%, 63%, and 69% increase when glass, steel, and PPS fibers were utilized	Strength will be low when there are high load-bearing requirements for large trucks or buses
Subashi, et al. [55]	Compressive strength and flexural strength	M15: 0%, 5%, 10%, 15% and 20% WRHA and M25: 0%, 5%, 10%, 15% and 20% WRHA	Compressive strength (56 days): M15 blocks was 28 MPa at 10% waste RHA; Improvement of 23%-33% flexural strength for M 15 blocks	Pervious concrete typically has a longer curing time compared to conventional concrete
Sarah, et al. [56]	Durability and porosity	RAP 25, RAP 50, RAP 75, and RAP 100	For durability properties, RAP mortar mixes experienced more shrinkage in comparison	Excessive water influenced the material's properties and performance
Praneet, et al. [57]	Compressive strength test and water absorption test	Normal mix, 10% R.H.A, 20% R.H.A, and 30% R.H.A	Compressive strength: At 30% RHA, the value was 9.52 Mpa (28 days) Water absorption test: At 30% RHA, the value was 6%	Pervious concrete lacks standardized test methods

However, such improvements in permeability are typically accompanied by reductions in mechanical strength, emphasizing the need for optimized mix design.

Rice Husk Ash (RHA) has also been extensively studied for its role in improving the sustainability and performance of pervious concrete. Fang et al. [45] investigated the partial replacement of ordinary Portland

cement with RHA in 13 different pervious concrete mixes, including both single and binary binder systems. The results indicated a significant reduction in carbon footprint, ranging from 9.9% to 20.6% per m³ of concrete, demonstrating the environmental benefits of RHA incorporation. In another study, Amrishi et al. [46] evaluated the effect of RHA in pervious concrete mixes and observed that the use of smaller aggregate sizes (4.75-10 mm) resulted in improved performance compared to larger aggregates (10-20 mm), likely due to better packing density and enhanced interfacial bonding. These studies highlight that RAP primarily enhances permeability through increased void connectivity but adversely affects mechanical performance due to weak interfacial transition zones, whereas RHA contributes to matrix densification, improved durability, and reduced environmental impact. The combined use of RAP and RHA therefore presents a promising approach for optimizing the strength-permeability balance in sustainable pervious concrete systems.

4.1 Mechanical performance of RAP and RHA in the pervious concrete

RAP is widely utilized as a sustainable alternative to natural aggregates in concrete systems due to its availability and environmental benefits [47]. Similarly, RHA, an agricultural by-product rich in amorphous silica, is employed as a partial replacement for OPC, contributing to enhanced sustainability and reduced carbon emissions [48,49]. The incorporation of RAP and RHA in pervious concrete necessitates a comprehensive evaluation of mechanical performance, as these materials significantly influence both structural integrity and functional behavior. The mechanical performance of pervious concrete is typically assessed through key parameters, including compressive strength, flexural strength, durability, and permeability, which collectively govern its suitability for pavement applications [50]. Although tensile strength is less emphasized in pervious concrete due to its low paste content and high porosity, flexural behavior remains critical for evaluating resistance to cracking under service loads. The inclusion of RAP introduces notable changes in mechanical performance. The presence of aged bitumen coatings and adhered fines on RAP aggregates leads to the formation of weak ITZ, resulting in reduced compressive and flexural strength. In contrast, RHA contributes positively to the mechanical behavior of pervious concrete through its pozzolanic reactivity. The reaction between silica in RHA and calcium hydroxide released during cement hydration leads to the formation of additional C-S-H gel. This process enhances matrix densification, improves interfacial bonding, and contributes to long-term strength development and durability. Furthermore, the fine particle size of RHA provides a filler effect, refining pore structure and reducing microcracking. The combined incorporation of RAP and RHA presents a synergistic approach, where the adverse effects of RAP on strength can be mitigated by the densification and bonding improvements induced by RHA. However, achieving optimal performance requires careful control of mix proportions, RAP replacement levels, and the use of suitable admixtures to ensure adequate workability, strength, and durability [51,52]. Therefore, a systematic evaluation of mechanical and durability properties is essential to ensure the effective application of RAP-RHA-based pervious concrete in pavement systems. Table 2 summarizes previous research studies, highlighting their key findings, performance trends, and identified limitations.

Further insights into the influence of Rice Husk Ash (RHA) on the mechanical performance of pervious concrete have been reported in recent studies. The effect of varying RHA replacement levels on compressive strength indicates that an optimal replacement of 10% RHA yields higher compressive strength compared to 8% RHA. This improvement is attributed to the enhanced pozzolanic reactivity and filler effect of RHA, which contribute to matrix densification and improved interfacial bonding within the concrete structure [58]. In addition to compressive behaviour, the flexural performance of pervious concrete incorporating hybrid supplementary materials has also been examined. The flexural strength of pervious concrete modified with RHA and calcium carbide waste (CCW) was evaluated by partially replacing cement with 0-10% RHA and 0-20% CCW at curing ages of 3, 7, and 28 days [59]. The results indicate that the combined use of RHA and CCW significantly influences flexural strength development, demonstrating the effectiveness of hybrid systems in enhancing mechanical performance. The variation in flexural strength with different replacement levels is illustrated in Figure 4. It is observed that the incorporation of Rice Husk Ash (RHA) and calcium carbide waste (CCW) in pervious concrete positively influences flexural strength at 3, 7, and 28 days of curing. Among the mixes, Mix 1 exhibited the lowest flexural strength, whereas mixes 3, 5, 7, 9, 12, and 14 demonstrated comparatively higher strength values, indicating the beneficial effect of combined RHA and CCW incorporation.

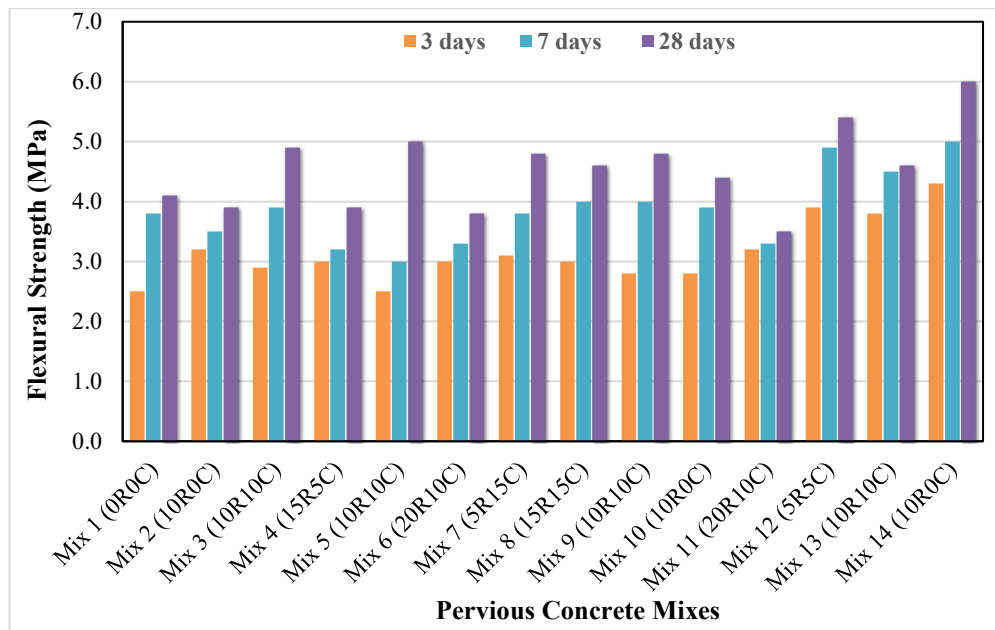


Figure 4: Flexural strength of pervious concrete incorporated with CCW and RHA

Recent studies have explored the combined incorporation of Reclaimed Asphalt Pavement (RAP) and Rice Husk Ash (RHA) in pervious concrete systems. The engineering properties of pervious concrete incorporating RAP and RHA have been evaluated by partially replacing cement and natural aggregates with RHA (up to 20%) and RAP (up to 50%) [60]. The results indicate that a combination of 15% RHA and 20% RAP yields improved mechanical performance, demonstrating a favourable balance between strength and material sustainability.

Further investigations into hybrid admixture systems have also been reported. The incorporation of RHA in combination with metakaolin has been shown to enhance the mechanical properties of pervious concrete through optimized mix design approaches [61]. Using a response surface methodology, an optimal RHA content of approximately 9.2% was identified, contributing to improved strength performance due to enhanced pozzolanic activity and matrix densification. In addition to mechanical strength, permeability remains a critical parameter governing the functional performance of pervious concrete. The water permeability of pervious concrete incorporating RHA and calcium carbide waste (CCW) has been evaluated using multiple mix combinations [62]. A total of 14 mixes were analysed, demonstrating the influence of supplementary materials on permeability behaviour. The variation in water permeability with different replacement levels is illustrated in Figure 5.

It was clear from Figure 5 that permeability values ranging from 0.96 cm/s to 1.11 cm/s will be fit for the

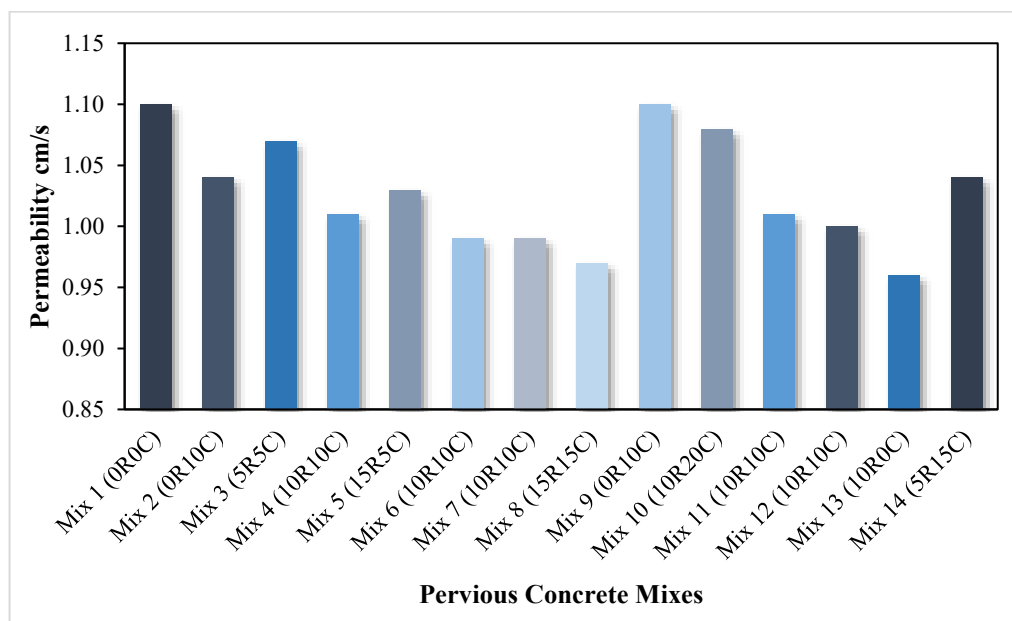


Figure 5: Water permeability of pervious concrete incorporated with RHA and CCW

pervious road pavement. 0% RHA and CCW, 0 % RHA and 10 % CCW, and 10 % RHA and 20 CCW % were the mix proportions that exhibited better performance in the analysis. The water permeability of the concretes was affected by the compaction as well as the gradation of the pore structure. It was also found that the water permeability of the pervious concrete was extremely high with different varying mix proportions.

5.Environmental Benefits of Using RAP and RHA in Pervious Concrete

The incorporation of Reclaimed Asphalt Pavement (RAP) and Rice Husk Ash (RHA) in pervious concrete offers significant environmental advantages by promoting sustainable construction practices and efficient resource utilization. Recycling asphalt pavements reduces the demand for virgin materials, lowers production costs, and minimizes construction-related waste generation [63,64]. Additionally, experimental investigations, including batch extraction and column flow studies, have been conducted to assess the environmental behaviour of unbound RAP, particularly in terms of leaching characteristics and long-term environmental impact [65,66]. The use of RAP and RHA in pervious concrete facilitates the beneficial reuse of industrial and agricultural waste materials that would otherwise require disposal. This approach significantly reduces landfill burden and contributes to sustainable waste management strategies [67,68]. The environmental benefits of RAP-RHA-based pervious concrete can be broadly categorized into reduced environmental impact, life cycle assessment (LCA), and resource conservation [69,70].

Reduced Environmental Impact: A primary focus of recent studies has been the reduction of environmental impacts associated with cement production through the incorporation of supplementary cementitious materials such as RHA [71]. The substitution of cement with RHA decreases carbon emissions and energy consumption, contributing to greener concrete production. Life cycle-based analyses of green concrete mixes incorporating RHA have demonstrated reduced environmental impacts, particularly due to lower cement content and associated emissions [72]. Furthermore, comparative assessments of dense and porous concrete systems indicate that the combined use of RAP and RHA results in lower environmental impacts while maintaining acceptable mechanical performance [73].

Life Cycle Assessment (LCA): Life cycle assessment provides a comprehensive framework for evaluating the environmental performance of pervious concrete across its entire lifespan. Studies have shown that incorporating RHA in pervious concrete yields both environmental and economic benefits, primarily due to reduced cement consumption and improved material efficiency [74]. Similarly, the use of RAP in pervious concrete has been associated with reduced environmental impacts in specific infrastructure applications, although certain construction stages may contribute significantly to overall emissions [75]. These findings highlight the importance of adopting a holistic life cycle perspective when evaluating sustainable pavement systems.

Resource Conservation: The utilization of RAP and RHA contributes directly to resource conservation by reducing the reliance on natural aggregates and cement. The incorporation of solid waste materials in pervious concrete supports sustainable urban construction by balancing material efficiency with environmental protection [76,77]. In particular, RHA serves as an effective partial replacement for cement, conserving natural resources while enhancing sustainability [78]. However, environmental factors such as temperature and relative humidity may influence long-term performance, indicating the need for careful consideration of service conditions.

6.Previous Survey Papers Related to RAP and RHA in the Pervious Concrete

A substantial body of research has been conducted on the utilization of RAP and RHA in pervious concrete systems. However, it is essential to critically examine existing review studies to identify research gaps and establish the distinct contribution of the present study. Previous survey papers have primarily focused on individual materials, generalized performance evaluation, or broader sustainability aspects, with limited emphasis on the combined interaction of RAP and RHA. Table 3 summarizes selected review studies, highlighting their key findings and limitations.

In contrast, the present study provides a comprehensive and integrated assessment of RAP and RHA in pervious concrete, emphasizing their synergistic interaction, microstructural mechanisms, and the resulting balance between mechanical strength, permeability, and durability.

This approach not only advances the current understanding of sustainable pervious concrete systems but also addresses critical gaps in existing review literature, thereby contributing to the development of optimized and environmentally resilient pavement materials.

Table 3: Previous survey studies related to the objective with its title, major findings, and limitations

Author name	Title	Findings	Limitations
Kunamineni, et al. [79]	Performance evaluation of reclaimed asphalt pavement (RAP) aggregate in concrete pavements: a state-of-the-art review	The review suggested that the utilization of pre-treated RAP aggregates can be used in the pervious or porous concrete. Adding supplementary cementitious materials (SCMs) will help to increase the overall performance.	A clear relationship between SCMs or fiber used and the mechanical characteristics of RAP concrete was not explored properly.
Anush, et al. [80]	Pervious concrete as a sustainable pavement material – Research findings and future prospects: A state-of-the-art review	Pervious concrete mix was a promising one to be used as a pavement material on low-volume roads.	Overall material and design standards were not properly explained in the analysis.
Elnaz, et al. [81]	Properties of pervious concrete incorporating fly ash as partial replacement of cement: A review	The compressive strength of the perceived concrete incorporating FA was decreased. This was due to the addition of FA that reduced the connection between the aggregates.	The impact of fly ash on the thermal and sound insulation of perceived concrete was not analyzed.
Eduardo, et al. [82]	Review of porous concrete as multifunctional and sustainable pavement	It was found from the review that a high performance-perceived concrete mixtures for specific applications can be designed	Optimizing the design of the mixtures to accomplish the integration of environmental characteristics of perceived concrete was not done.

7. Conclusion

The incorporation of RAP and RHA in pervious concrete offers a promising strategy for developing sustainable and high-performance pavement systems. The reviewed studies consistently indicate that RAP enhances pore connectivity and permeability, while RHA improves mechanical performance through pozzolanic reactions leading to the formation of additional C-S-H gel and matrix densification. However, the presence of aged asphalt coating on RAP aggregates results in weak ITZ, which limit bonding efficiency and reduce mechanical strength. Consequently, the development of effective and low-cost RAP treatment methods is essential to improve surface characteristics and enhance compatibility with the cementitious matrix. In parallel, the performance of RHA is highly dependent on its replacement level; while moderate dosages enhance strength and durability, excessive replacement reduces performance due to insufficient availability of $\text{Ca}(\text{OH})_2$ required for sustained pozzolanic reactions. The combined use of RAP and RHA demonstrates significant potential for achieving a balanced strength-permeability relationship, where the densification effect of RHA compensates for the strength reduction induced by RAP. In addition to performance enhancement, this approach contributes to environmental sustainability through resource conservation, waste utilization, and reduced carbon emissions. Despite these advancements, existing studies predominantly focus on isolated material effects, with limited investigation into the coupled interaction between RAP and RHA and their integration within the overall pavement system. In particular, the influence of these materials on subgrade interaction, drainage efficiency, and long-term field performance remains inadequately understood. Future research should therefore prioritize mechanistic and multi-scale investigations, including the development of optimized mix designs, cost-effective RAP treatment techniques, and long-term performance evaluation under realistic service conditions. Such efforts are critical for translating laboratory-scale findings into practical and scalable engineering solutions. The synergistic integration of RAP and RHA in pervious concrete provides a robust pathway toward sustainable pavement infrastructure, enabling the simultaneous achievement of mechanical performance, hydraulic functionality,

and environmental responsibility.

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