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Performance of Pervious Concrete Containing Reclaimed Asphalt Pavement Aggregate A-review

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Abstract

Increasing population , urbanization, and expanding infrastructure projects have led to a significant rise in construction and demolition waste (CDW), increasing the demand for raw materials and creating a need for effective waste management. Despite the environmental and economic advantages of recycling, the use of recycled aggregates in construction remains limited due to low awareness, weak regulations, quality concerns, and the lower cost of natural materials. With landfill space rapidly decreasing, recycling CDW particularly by incorporating Reclaimed Asphalt Pavement (RAP) into concrete is a sustainable solution. This study reviews the application of RAP in pervious concrete, highlighting its impact on mechanical properties, permeability, density, Abrasion resistance and porosity. While RAP tends to reduce mechanical strength and density, it lowers the demand for virgin resources and can cut environmental impact by 15–30%, with greenhouse gas emissions reduced by up to 17% when replacing 50% of natural aggregates.

Keyword. Pervious Concrete(PC), mechanical properties, Reclaimed Asphalt Pavement, Compressive Strength, Flexural strength, Permeability, review.

1. Introduction

Pervious concrete, recognized for its porous and permeable characteristics, has been utilized for an extended period. It attained prominence in the late 20th century as an eco-friendly substitute for conventional impermeable pavements. Because of its lower compressive strength than conventional concrete, its first applications were limited to nonstructural uses. [1]. This concrete variant is characterized by its elevated porosity, with interconnecting spaces generally constituting 15% to 30% of its volume, facilitating a water permeability of roughly 2–6mm/s.

Pervious concrete pavements are permeable surfaces that facilitate runoff management while functioning as the wearing course for low-traffic roads, parking areas, and pedestrian/bicycle walkways, among other uses. The recent rise in the utilization of pervious concrete, attributed to its advantages in stormwater management, necessitates the swift establishment of standardized acceptance tests appropriate for pervious concrete[2].

Pervious concrete has significantly contributed to mitigating urban waterlogging; nonetheless, the ongoing accumulation of obstructions, such as sediment, diminishes its permeability, ultimately transforming it into impervious concrete pavement. Consequently, its permeability is effectively reduced, rendering it devoid of actual technical significance. Consequently, studying the mechanical properties of pervious concrete is crucial for achieving low-carbon urban development[3].

The growing emphasis on sustainable creation techniques and the use of environmentally pleasant substances has augmented interest in pervious concrete, alongside its economic blessings. Advancements in materials technological know-how and concrete era have improved its overall performance and consistency. Pervious concrete is defined by using its porous shape and hydrological properties, allowing it to have interaction with water in approaches that normal concrete can not. These residences align effectively with modern engineering practices that prioritise performance and environmental sustainability, consequently improving its recognition as a novel creation fabric [4].

Reclaimed Asphalt Pavement (RAP) denotes existing asphalt materials obtained during road rehabilitation, resurfacing, or reconstruction activities. Upon extraction, the material is classified as RAP, containing useful components such as high-quality aggregates and aged asphalt binder. Reclaimed Asphalt Pavement is widely utilised worldwide in recycled asphalt mixtures to improve sustainability and reduce building costs. It can be produced either through cold milling using a spinning

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drum equipment or by ripping and crushing existing pavement layers. Reclaimed Asphalt Pavement (RAP) typically consists of around 93–97% natural aggregates by weight, encased in aged bitumen, with the remaining 3–7% including residual cured asphalt binder. [5].

The development of strategies to eradicate greenhouse gasses is crucial, and sustainability must be the main priority. The most widely used building material, concrete has the biggest environmental impact throughout both the production and dismantling phases. The significant energy consumption associated with the production of concrete draws attention to the issue of greenhouse gas emissions, particularly CO_2. The most energy-intensive step in the process is the manufacturing of cement, which uses 90% of the energy in concrete. Construction and Demolition Waste (CDW) is the main source of garbage output worldwide, amounting up 25–30% of all material waste [6].

Recycled asphalt pavement, including aggregate and bitumen from aged asphalt pavement, is produced in substantial volumes annually as waste material. Recycled Asphalt Pavement has been employed as a resource in construction projects, thereby substantially diminishing the environmental impact. In this context, RAP was utilized as a partial substitute for aggregates in cement concrete.

2. Application of previous concrete :

- Previous concrete lacking reinforcement is susceptible to degradation due to its porous composition[7].
- Pervious concrete's higher pore density considerably lowers its compressive strength, which restricts its use for high-traffic pavement applications. This structural deficiency may result in early degradation under substantial loads, rendering it more suitable for low-traffic zones such as pedestrian walkways, parking areas, and landscaping uses. Further research is required to investigate reinforcement techniques, optimum mix designs, or the integration of other materials to augment its strength and broaden its use[8].
- Pervious concrete is frequently utilized in low-traffic environments, including roads, walkways, driveways, parking lots, swimming pool decks, tennis courts, drainage systems, zoo areas, highway pavements, greenhouse floors, and several other applications. The positioning of pervious concrete is crucial, and specialized methods are employed to ensure optimal performance is achieved[7,9,10].

3. Properties of RAP Aggregate

3.1. Gradation

Grain size diameters (D60, D30, D10) and other important characteristics, like the acceptable percentage, are specified using the RAP gradation. Processor approach has a significant impact on RAP's gradient. RAP is processed to different particle sizes based on the use for which it is designed. The extensive application of RAP in asphalt mixtures requires that its primary gradation meet the requirements specified in the particular mixture design. Generally speaking, 50 mm is the maximum acceptable aggregate size. Nonetheless, the majority of RAP gradations comprise particle sizes of 25 mm or smaller[11].

3.2. Specific Gravity and Water Absorption

Aggregate specific gravity (SG) as the ratio of the weight of aggregate to the weight of water at a specified volume. The density of RAP materials comprising aggregate and aged bitumen is affected by the specific gravity of the components and their composition. The presence of old bitumen diminishes the density of RAP [12].

RAP specific gravity varies throughout investigations, possibly as a result of various milling methods. It was demonstrated that RAP has a lower specific gravity than traditional coarse-grained aggregate materials. [11].

The density consistently diminished as the proportion of RAP aggregates escalated from 25% to 100%. This may result from the reduced specific gravity of RAP aggregates compared to natural coarse aggregates (NCAs). Moreover, the rigid asphalt layer in coarse RAP would have resulted in diminished cohesion and intermolecular interactions among the particles[13].

The water absorption capacity of RAP aggregates surpassed that of virgin aggregates owing to a dust contamination layer around the RAP particles. This layer required further mixing of water, resulting in a notable elevation in the optimal moisture content of the mixture relative to the control mix[14].

The particulate matter in RAP, originating from an unregulated milling process, was shown to be highly water-saturated, hence substantially increasing the absorption capacity of RAP[15]. The presence of old bitumen further hinders water absorption into the RAP pores [12]. **Table 1** Physical properties of RAP when compared to natural aggregates.

Table 1: The physical characteristics of Reclaimed Asphalt Pavement (RAP) Compared with Natural Aggregates.

Aggregate properties	Behavior concerning the control	References
Specific Gravity(SG)	Reduce	[17]
Water Absorption	Higher	[15,16,17]
Unit Weight	Reduce	[18]
Grading	finer	[15,17,19]
Fineness Modulus	Higher	[15,20]
Crushing Value	Reduce	[15]
Impact Value	Reduce	[15,21]

3.3.Asphalt Content

Asphalt comprises a blend of many constituents. The composition consists of aggregates and a binder. Asphalt yields a robust, resilient, and pliable substance[22].The usual asphalt content is between 4.5% and 6% for RAP[23].

The addition of a reduced-density asphalt layer encasing. Aggregates reduce the total weight of the RAP matrix; hence, using both RAP fractions, individually or combined, may result in a lower-density concrete mixture. [24].

To alleviate the effects of oxidation of the asphalt layer surrounding the particles, the RAP material promptly transported to the laboratory upon reclamation without any interim stockpiling. The oxidation of RAP during service and storage leads to the hardening of the asphalt layer[25]. The solidification of the asphalt layer surrounding the RAP may enhance unbound granular mixtures and cement concrete mixtures[17,26].

4. Mixing design

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The proportions of the mixture for pervious concrete vary from those of conventional concrete., as the mixing design should facilitate the creation of voids inside the concrete structure to improve permeability. The mixing designs for previous concrete predominantly depend on empirical approaches or a trial-and-error approach, owing to the lack of definitively established criteria for this concrete type. It is imperative to finalize the installation procedure expeditiously, as pervious concrete possesses a small water content, rendering it more vulnerable to moisture loss when subjected to prolonged weather exposure. This loss can diminish the water necessary for hydration, adversely affecting the cohesion and structural integrity of the combination. Consequently, regulating the placement and curing conditions is essential for achieving the requisite performance regarding strength, durability, and permeability[27].

4.1.Fresh Properties of PC Containing RAP

The working time for fresh pervious concrete is less than that of conventional concrete [28]. When making use of admixtures including hydration stabilisers or retarders, casting must occur within one and a half of hours. The period may additionally vary relying on factors including ambient temperature and the quantity of admixtures used. The decreased operating time for pervious concrete is a vital trouble, since it without delay affects and site, which are crucial for achieving the desired compaction in the final final results. Effective management of operating time is crucial to prevent premature putting and ensure the satisfactory of the concrete blend in practical programs [29]. To assess the mould ability of pervious concrete, its workability must be evaluated using a ball grasped in the hand, as depicted in **Figure 1** The workability of pervious concrete is significantly influenced by water content; thus, meticulous regulation of water volume is crucial for attaining the necessary consistency and performance[30].

Effective management of the mixing and casting process is essential for maintaining the structural integrity, durability, and permeability of pervious concrete. Following prescribed parameters enhances performance, averting problems like inadequate hydration or cohesion loss that may jeopardize the overall integrity of the finished structure.

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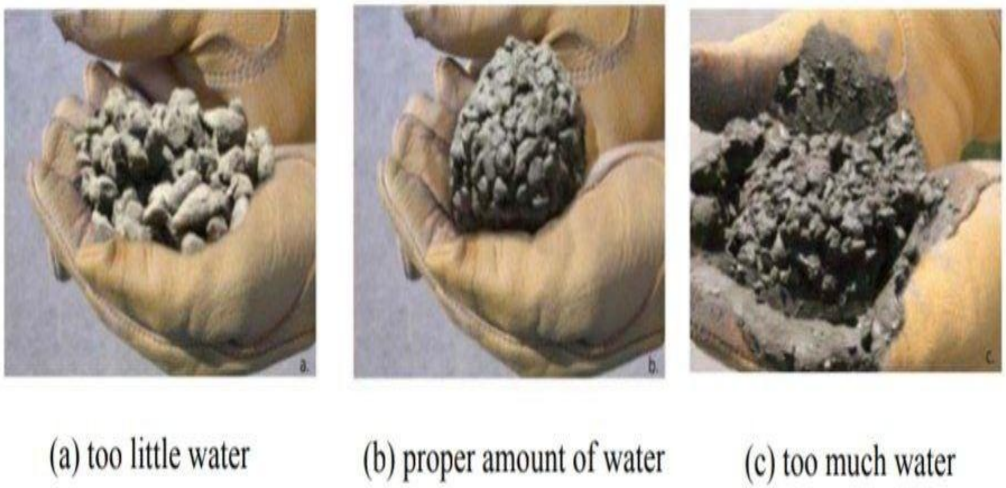

Fig. 1 the workability of pervious concrete[31].

5. Mechanical properties

5.1.Compressive Strength

Permeable concrete exhibits a compressive strength of MPa (2.8-28) after 28 days, which is substandard compared to regular concrete because of its intrinsic vacancy structure[27]

A study [32] that revealed 28-day compressive strengths ranging from 3.7 to 12.8 MPa. The research demonstrates The compressive strength for 28 days of samples incorporating RAP content Diminished in each mixture, with an increasing proportion of RAP. This issue may arise from the coarse RAP aggregates having inadequate aggregate-to-cement bonds due to the encasing inflexible asphalt layer.

The presence of RAP at varied concentrations causes a considerable reduction in compressive strength, and this drop occurs regardless of the age at which the material is cured. As a result of the diminished interparticle connections of RAP aggregates, which are encased in a rigid layer of asphalt, the aggregate-to-cement link is reduced. The fact that RAP aggregates are encased in asphalt may explain this feature[13].

Researchers Saboo et al. [29] noted that an increase in the quantity of Reclaimed Asphalt Pavement (RAP) correlated with a decrease in compressive strength. The study suggested substituting 50% of the coarse aggregate with RAP, as traditional coarse aggregate typically deteriorates in strength when subjected to H_2SO_4 ions in an HCl solution. The aim of this study was to create pervious concrete (PC) that can endure severe environmental conditions, including acidic and polluted settings. The integration

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of RAP improves the concrete's resilience to chemical deterioration while providing a sustainable option that mitigates the exhaustion of natural resources and reduces construction waste.

As the quantity of RAP aggregate rises, the compressive strength diminishes. The reduction is attributable to multiple factors: the asphalt layer surrounding the aggregate, which results in inadequate adhesion between the aggregate and the cement paste; The existence of aggregate particles on the surface roughness of the RAP aggregate has deteriorated due to asphalt layers. Elucidate the formation of a deficient interfacial transition zone (ITZ) at the interface between cement paste and recycled asphalt pavement (RAP) aggregates. This region functions as the contact between the two chemicals[9].

After 28-day curing period, the highest compressive strength reported in the scientific literature was 65.80 MPa. The material was consolidated in three strata utilizing light vibration and three impacts per stratum with a Proctor hammer [33], The findings reveal a composition including 19.8% air voids, an aggregate size of 1.19 mm, and a water-to-cement ratio of 0.22, comprised of cement, silica fume, silica powder, and water-reducing additives. An evaluation of the adhesive properties of cementitious materials incorporating asphalt-coated particles revealed that reduced strength in the Interfacial Transition Zone (ITZ) around the recycled asphalt pavement (RAP) aggregates leads to increased porosity. The cohesive failure of the asphalt overlay on the aggregates is mostly owing to increased porosity in the interfacial transition zone surrounding the RAP at the time of cracking, rather than a failure at the cement-asphalt interface. [20]. This serves as the primary justification for the overall failure of the asphalt overlay.

5.2.Flexural Strength

It is essential to investigate the flexural behavior of pervious concrete mixtures, as it is a critical design parameter for determining the pavement slab thickness. The flexural strength of pervious concrete can vary from 1.0 MPa to 3.8 MPa[29].

Flexural strength data were assessed in a study conducted [32]. RAP concrete's flexural strength dropped as the quantity of RAP material in the mixture increased. The flexural strength of the samples with 10%, 20%, 50%, and 100% RAP fell by 14.2%, 7.1%, 16.9%, and 46.4%, respectively. in comparison to the control concrete. [13] exhibit The flexural strength diminishes with an increase in

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the fraction of coarse RAP particle assimilation. The concrete mixtures with RAP exhibited greater hardness than the control mixtures.

Even though there was no coarse RAP aggregate in the mix [29], the results were still the same. More excellent mix toughness is achieved as a result of the weight of the vehicle being absorbed by the rigid layer of RAP binders that surrounds the aggregates. This layer also restricts the maximum stress that can be applied to the standard aggregate. According to [13], the flexural strength of the material is significantly reduced when there There is a lesser degree of interlocking of the cement and the aggregate.

5.3 . Modulus of elasticity

Porosity affects the rheological, mechanical, and hydraulic properties of pervious concrete. The modulus of elasticity is an important property that is used to evaluate the mechanistic response of any material when it is subjected to load.

According to Bttencourt et. al [32] The modulus of elasticity of pervious concrete is contingent upon its strength characteristics, void distribution, and the stress intensity applied during the modulus testing of the material. As a result, PC samples with equivalent compressive strength may have different modulus of elasticity values due to changes in void distribution and stress levels generated during testing. The simplified physical models of PC consist of three elements: the pore, the aggregate, and the binder. Demonstrated the dynamic elastic modulus of PC is correlated with the material's porosity through a linear function[35].

Saboo et. al [29] Irrespective of the quantity of RAP utilized, a diminished elastic modulus is noted in RAP concretes, exhibiting reductions of 21% (10% RAP), 30% (20% RAP), 55% (50% RAP), and 86% (100% RAP) after 28 days in comparison to the control combination.

6. Permeability

The permeability properties are among the most essential qualities of pervious concrete[36], indicating the ability of surface water to permeate the pervious concrete pavement system. It is widely accepted that heightened porosity is associated with greater results. There is often a linear or idempotent relationship between porosity and the permeability coefficient. On the other hand, when aggregate size grows, the permeability coefficient rises with equal porosity. Permeability increases with aggregate particle size, and continuous and mixed-graded coarse aggregates have lower permeability

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coefficients than single-graded coarse aggregates.. Similarly, concrete made with finer aggregates that demonstrate superior grading increases its strength and decreases water permeability[37].

Increased permeability can be achieved by removing fine aggregate, constructing single-sized graded mixes, or utilizing double-sized graded mixes with a gap in the grading[38].

Sahdeo et. al [13] investigated the permeability characteristics of pervious concrete including recycled asphalt pavement (RAP) using a proprietary falling head permeability test in compliance with[27], Specimens were utilized,The intermolecular interaction between the RAP aggregates and cement paste was insufficient due to the rigid, thick asphalt covering surrounding them. Consequently, the enhancement in permeability of the samples occurred in the subsequent sequence: 100% RAP is greater than 75% RAP, 50% RAP, 25% RAP, and Control Mix.

RAP aggregate is frequently coarser and uneven, which increases water movement through concrete. In other circumstances, RAP aggregate may not adhere to cement as well as natural aggregate, thereby increasing the amount of open water channels[37]. Voids in concrete shrink with time as the hydration process continues. This explains why permeability declines with aging[13].

7. Porosity

Porosity is regarded as the most critical physical property influencing practically all durability characteristics of cement concrete mixtures. An elevated void concentration results in enhanced porosity and increased water absorption capacity in the concrete mixtures[26].

According to Ulloa-mayorga et. al [39] the porosity of pervious concrete that is made using recycled aggregates and has numerous angles is frequently higher than the intended porosity and higher than the porosity that is achieved when using regular aggregates. Akkaya and Çağatay [41] conducted a study that shown that recycling concrete did not have an effect on the porosity of the material, but it did reduce the density of the concrete and enhance its water permeability.**Figure 2** shows the pores in a PC.

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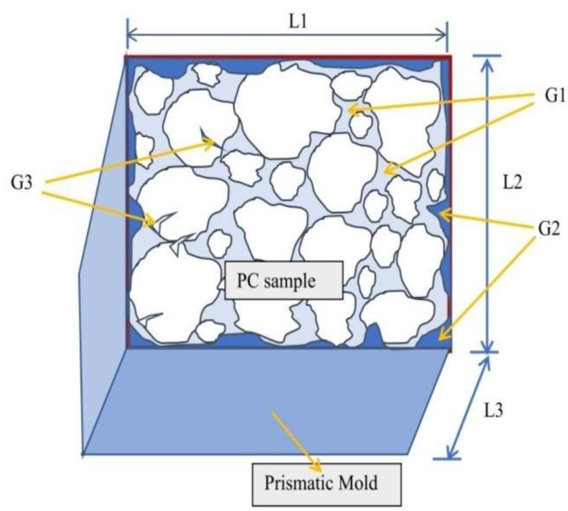

Fig. 2 Void content in PC [13,41]

8. Density

No significant change in density occurs when modifying aggregate grading or the amount of cement replaced with fly ash. The results indicate a positive trend, as the porosity of pervious concrete decreased with an increase in density[42].

The study noted a reduce in the density of Pervious concrete with different amounts of RAR in the concrete. This decrease is because the inferior density of RAP aggregate. [32].

As the proportion of RAP aggregates increased from 25% to 100%, the density consistently decreased without variation. This reduction can be attributed to the lower specific gravity of RAP aggregates compared to natural coarse aggregates (NCAs). The existence of a rigid asphalt layer atop coarse RAP likely reduced cohesiveness and diminished intermolecular interactions among the aggregates. The rise in RAP content highlighted the inadequacy of adhesion. [13].

Meddah et. al [43] demonstrate that in order to create pervious concrete, some of the natural aggregate was swapped out for recycled aggregates made of different materials, such as rubber, crushed seashells, crushed glass, shredded plastic, and ferrochrome. Because recycled aggregates have a different shape and a lower specific gravity than native aggregates, their use resulted in a drop in the density of the pervious concrete. Because rubber has a low specific gravity and can fill holes, rubberized pervious concrete had the lowest density of all the combinations, measuring 1700 kg/m³. In

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contrast, pervious concrete with natural particles retained on a 5 mm filter had a moderate density of 1735.3 kg/m³ and the maximum porosity of 32.6%.

9. Abrasion resistance

Study by Sahdeo et. al [13] on abrasion resistance indicated that mixtures including recycled RAP materials demonstrated greater mass loss than the control mix following 28 days of moist curing. Reports suggest that the mass loss following abrasion was approximately 23.5%, 28.9%, 33.4%, and 38.7% for mixtures including 25%, 50%, 75%, and 100% RAP, respectively. This indicates that elevating the RAP concentration results in a notable decrease in abrasion resistance relative to traditional combinations, underscoring the necessity for additional study to improve the efficacy of these mixes in practical applications The values are significantly elevated compared to the control specimen, with increases of roughly 8.9%, 14.3%, 18.9%, and 24.1% for RAP concentrations of 25%, 50%, 75%, and 100%, respectively. The considerable increase in mass loss is presumably due to the rigid asphalt layer encasing the aggregates, along with its hydrophobic properties. These elements diminish the link between the aggregate and cement, thereby decreasing the total cohesiveness of the mixture. The RAP-PCP specimens demonstrated a gradual escalation in material loss during the Cantabro abrasion test.

Table 2 shows the effects of RAP on PC.

Table 2 The effects of RAP on PC.

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PC Property	There is a correlation between the amount of RAP in concrete and the effect on property.	References
Compressive Strength	(5–25 MPa)	[13,,29,32,44,]
Flexural strength	(1–3.2 MPa)	[13,32,44]
Modulus of elasticity	Reduce	[29,44]
Split Tensile	Reduce	[44]
void content	There was a greater increase in the levels of 50%RAP and 100%RAP samples (up to + 13.4%).	[32]
Abrasion resistance	The service life of concrete is being decreased	[13]
density	A decrease in concentration (between 1.68 and 1.90 g/cm3)	[13,32]
Porosity	Increase	[13,32]
permeability coefficient	Reduce	[13,32]

10.Conclusion

The following can be concluded from the inclusion of RAP aggregate in PC:

The mechanical properties (compressive strength, flexural strength, Split Tensile, and modulus of elasticity) of PC decrease as the amount of RAP in the mix increases. This is due to the weak adhesion between the aggregate and the cement paste, caused by the asphalt layer encasing the aggregate, along with the lower specific gravity of recycled asphalt pavement (RAP) compared to natural aggregate, diminishes the strength and durability of the mixture. The permeability and porosity coefficients increase with increasing amounts of RAP. This, in turn, is due to the un compacted nature of RAP, which creates pores in the mix, and to the weak bond between the RAP aggregate and the cement mortar. The density decreases with increasing amounts of RAP. This, is due to the decrease in the

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specific gravity of RAP and the increase in its porosity. Augmenting the quantity of RAP in the mixture leads to a substantial reduction in abrasion resistance, attributable to the deterioration of the bond between the aggregate and the cement paste caused by the asphalt layer encasing the aggregate. Consequently, additional research is required to augment the bonding characteristics and elevate the abrasion resistance of these mixtures.

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