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Original Article

Pervious Concrete Using Treated Reclaimed Asphalt Pavement: Impact of Different Treatment Durations

Gyanen Takhelmayum[1], Konsam Rambha Devi[2]

[1,2]*Department of Civil Engineering Manipur Institute of Technology, Manipur University, Imphal, Manipur, India.*

[1]*Corresponding Author : rkonsam.mit@manipuruniv.ac.in*

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Abstract *- This study examines the influence of Reclaimed Asphalt Pavement (RAP) treatment duration on the structural integrity and hydraulic efficiency of Pervious Concrete (PC) mixtures based on a 28-day curing period. RAP replacement levels ranged from 0% to 100% in 25% increments, with treatment durations of 0, 12, and 24 months. The findings revealed a 6%-7% decrease in density and a 20%-28% increase in porosity. Permeability significantly improved, increasing by up to 55% with higher RAP content. However, compressive and flexural strengths declined by 40%-45% at full RAP replacement, though longer treatment durations led to a strength recovery of up to 10%. While greater RAP content enhances permeability, it adversely affects strength and density. Scanning Electron Microscopy (SEM) analysis showed noticeable microstructural changes over the treatment period. However, extended RAP treatment alleviated these effects, making treated RAP a sustainable and viable material for pervious concrete applications requiring both hydraulic efficiency and structural reliability.*

Keywords *- Compressive strength, Flexural strength, Hydraulic permeability, Pervious Concrete, Recycled Asphalt Pavement.*

1. Introduction

Traditional concrete pavements have faced criticism for their inadequate stormwater management, which contributes to issues such as groundwater contamination [1-6]. Additionally, these traditional pavements play a major role in the development of Urban Heat Islands (UHI), exacerbating environmental challenges in densely populated regions [7-9]. To mitigate these issues, Pervious Concrete (PC) has gained attention as a viable alternative due to its porous structure, which allows for efficient stormwater infiltration and retention [10].

The construction sector faces growing pressure to implement sustainable practices, particularly due to regulations restricting quarrying activities [6, 11]. These limitations led the industry to explore alternative aggregate sources to fulfill infrastructure needs while minimizing environmental impact. One promising alternative is Reclaimed Asphalt Pavement (RAP), a by-product generated during the maintenance and rehabilitation of bituminous roads. [12, 13].

However, integrating RAP into the concrete matrix generally leads to reduced mechanical performance compared to Natural Aggregates (NA), mainly due to weak bonding between RAP and cement mortar caused by the existence of a stiff asphalt layer [14-17]. To address this issue, researchers have explored various techniques to eliminate or treat asphalt coating, enhance the bonding between Reclaimed Asphalt Pavement (RAP) and cement mortar, and improve the mechanical properties [6, 12]. Treated RAP has received growing attention in recent years, creating an opportunity for the industry to expand its application in construction [18]. Previous research shows that chemical etching, such as soaking RAP in turpentine, fails to improve bonding with cement mortar. Although chemical oxidation enhances adhesion, its high cost restricts large-scale application [19].

This study introduces a cost-effective pre-treatment method for Reclaimed Asphalt Pavement (RAP) using solar heating, natural oxidation, and Abrasion and Attrition (AB&AT) method to enhance its integration into Pervious Concrete (PC) mixtures. The use of treated RAP aims to improve PC performance while promoting sustainable construction practices. Its incorporation contributes to eco-friendly infrastructure development, effectively addressing key environmental challenges.

2. Experimental Design

2.1. Components

Ingredients employed in this investigation to create Pervious Concrete (PC) mixes include cement, Natural Aggregates (NA), Reclaimed Asphalt Pavement (RAP), water, and a superplasticizer. The cement properties are displayed in Table 1, and those of NA as well as RAP are listed in Table 2. Both RAP and NA aggregates, with gradations of

12.5-10 mm and 6.3-4.75 mm, were used, as shown in Table 3. RAP aggregates were treated for 0, 12, and 24 months to enhance their properties. The RAP treatment process was designed to enhance material properties through controlled thermal conditioning and oxidation cycles. The 12-month treatment involved two cycles of thermal exposure in a custom-built solar oven (40°C–70°C), monitored via temperature sensors and followed by natural accelerated oxidation in an open environment. This process was repeated quarterly, with dust removal using a water jet to maintain particle cleanliness. The 24-month treatment extended over eight quarters, completing four cycles of alternating thermal treatment and oxidation exposure. Following both treatment durations, RAP underwent surface modification through mechanical roughening using the AB&AT technique to improve adhesion characteristics. Potable water was used for both the manufacturing and curing processes. Additionally, Sunanda Polytancrete NGT superplasticizer was utilized to enhance the PC mix's workability.

2.2. Items of Investigation

Density and porosity were evaluated according to [20]. Compressive strength was assessed in compliance with [21]. Additionally, flexural strength was evaluated using the two-point load method as per [21]. The falling head permeability test was performed in accordance with the prescribed standards [23]. The testing arrangement is shown in Figure 1.

Table 1. Physical characteristics pertaining to Ordinary Portland Cement (OPC)

Properties	Test Result	Recommendations as per IS Codes	Test Method
Consistency (%)	33	25-35%	IS: 4031 (P-4)
Fineness (%)	3.10	<10%	IS: 4031 (P-1)
Initial Setting Time (min)	65	>30 min	IS: 4031 (P-5)
Final Setting Time (min)	280	<600 min	IS: 4031((P-5)
Specific Gravity	3.13	3.1-3.16	IS: 4031 (P-11)

Table 2. Material characteristics pertaining to NA and RAP Aggregates

Properties	NA		RAP						Testing Standard
			0 Month		12 Months		24 Months		
	10mm	4.75mm	10mm	4.75mm	10mm	4.75mm	10mm	4.75mm	
Specific Gravity	2.638	2.504	2.478	2.313	2.499	2.379	2.552	2.49	IS 2386-3
Impact Value (%)	17.754	-	12.07	-	10.678	-	8.85	-	IS 2386-4
Crushing Value (%)	14	15.6	18.21	17.3	17.89	16.24	17.15	16.11	IS 2386-4
Asphalt Content (%)	-	-	2.8	3.2	2.14	2.9	1.95	2.85	IS 13826-2

Table 3. Mix proportions for pervious concrete comprising NA and RAP

Composition (%)	W/C Ratio	C/A Ratio	Superplasticizer (% by Weight of Cement)	NA Kg/m^3		RAP Kg/m^3		Cement (Kg/m^3)	Water (Kg/m^3)
				10-12.5 mm	4.75-6.3 mm	10-12.5 mm	4.75-6.3 mm		
Control Mix	0.36	1:4	0.3	470.18	1097.10	**0**	0	391.82	137.13
25 RAP	0.36	1:4	0.3	386.14	772.28	154.45	231.68	386.14	135.14
50 RAP	0.36	1:4	0.3	227.34	530.47	227.34	530.47	378.91	132.61
75 RAP	0.36	1:4	0.3	149.42	224.13	373.55	747.1	373.55	130.74
100 RAP	0.36	1:4	0.3	**0**	**0**	441.12	1029.28	367.6	128.66

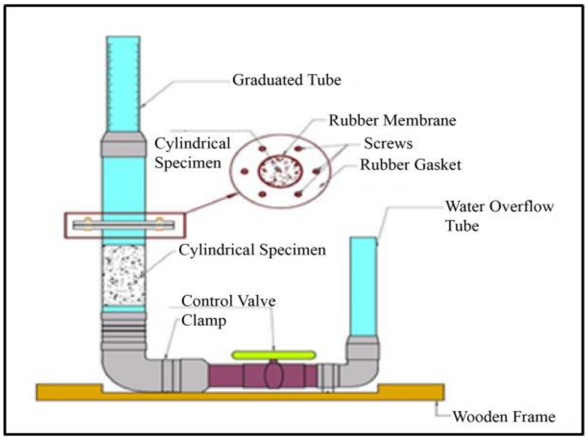


Fig. 1 Specifically designed falling head permeability test setup

3. Findings and Interpretation

3.1. Functional Properties

The assessment of density and porosity is crucial in PC mixes because these two parameters are inversely proportional and are key indicators of Pervious Concrete (PC) performance [24]. Figures 2(a) and (b) illustrate the changes in the density and porosity of PC as the RAP content increases across various treatment periods.

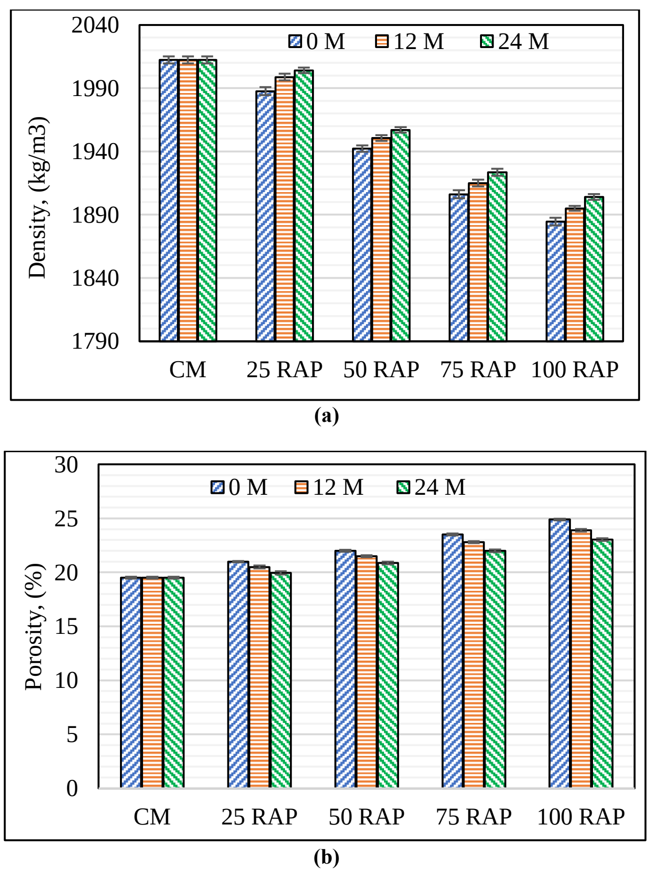


Fig. 2 (a) Density, and (b) Porosity of pervious concrete with increasing rap content across different treatment periods (error bars indicate standard deviation).

In mixes in which natural aggregates are replaced by RAP, raising the RAP content results in a noticeable decrease in density. For instance, the control mix, containing 0% RAP, which decreases progressively with RAP content at 100% RAP, represents a 6.3% reduction. A gradual rise in density was noted at all RAP replacement levels when subjected to extended pre-treatment durations. This is due to the removal of the asphalt binder during the treatment process, which enhances the bonding and compaction of the aggregates. At 25% RAP, density rises from 1987.65 kg/m³ at 0 months to 2004.12 kg/m³ at 24 months, and similarly, at 100% RAP, it shows an increase over time, maintaining values within the prescribed limit of PC densities.

In contrast, porosity increased with higher RAP content (Figure 2(b)). The porosity of the control mix (0% RAP) was 19.5%, which rises to 24.9% at 100% RAP, reflecting an increase of 27.7%. Porosity experienced a slight decrease over time, such as at 25% RAP, where it decreased from 21% at 0 months to 19.96% at 24 months. Importantly, the porosity values across all RAP levels, including 100% RAP, remained within the typical range of 15% to 30% for PC mixes, ensuring that the material’s functional performance was maintained.

3.2. Permeability

The effectiveness of a PC mix relies heavily on the degree of void interconnectivity and aggregate bonding within the mixture. As shown in Figure 3, which demonstrates the permeability of PC as it increases the RAP composition over different treatment periods, the permeability shows a rise with the corresponding proportion of RAP in the blend. For the 0% RAP mix (control mix), the permeability remains steady at 0.233 cm/s.

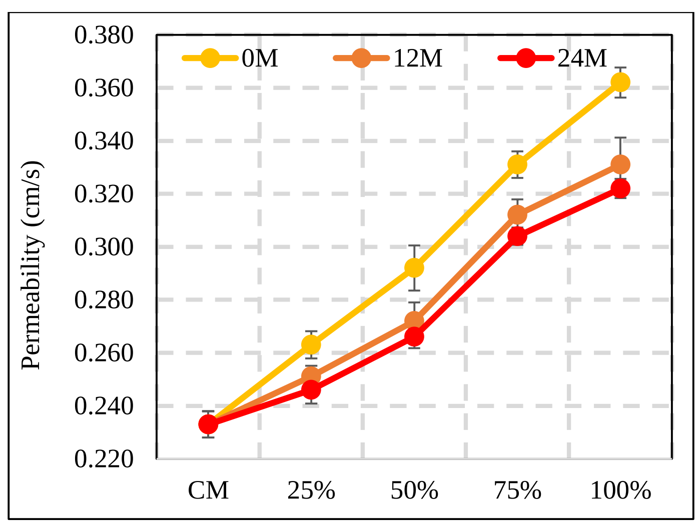


Fig. 3 Permeability of pervious concrete with increasing rap content over different treatment periods

However, at 25% RAP content, permeability exhibited an initial improvement, showing a 12.9% increase compared to the control mix. Over time, this value gradually decreased, reaching 7.7% at the 12-month mark and 5.6% after 24 months of treatment. As the RAP content reached 50%, the initial rise in permeability was more pronounced, with a 25.3% increase observed at 0 months. Despite this, the permeability began to decrease over time, showing a 16.7% increase at 12 months and levelling out at 14.2% after 24 months.

Similarly, at 75% RAP, the permeability reached its peak, with a significant increase of 42.1% initially. This higher permeability began to taper off with time, dropping to 33.9% at 12 months and 30.5% after 24 months. The highest permeability was recorded with 100% RAP replacement, where an initial increase of 55.4% was observed. However, with lower RAP content, the permeability decreased with extended treatment, showing a reduction of 42.1% after 12 months and 38.2% at 24 months. This increase in permeability with higher RAP content is attributed to the hydrophobic properties of asphalt, which promotes water flow through the interconnected voids.

3.3. Compressive Strength

Figure 4 shows the compressive strength of the PC, which shows a noticeable decline with increasing levels of RAP replacement. At 25% RAP, the strength showed a 17.4% reduction at the 0M treatment period compared with the control mix.

This reduction diminishes to 9.6% at 12M and to 11.4% at 24M. With 50% RAP, the reduction in strength was 28.7% at 0M, but this improved over time, with reductions of 21.6% at 12M and 18.0% at 24M, highlighting the effect of the extended treatment period.

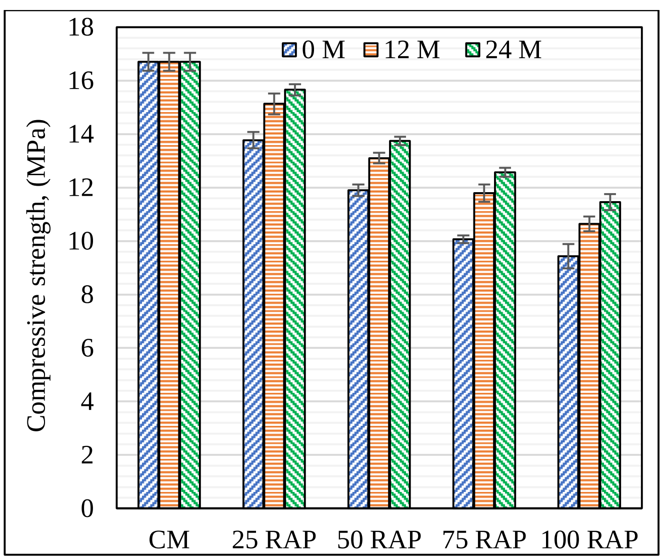


Fig. 4 Compressive strength of RAP-modified mixes under varying treatment periods (error bars indicate standard deviation)

For 75% RAP, the compressive strength decreases by 39.5% at 0M, though the reduction lessens to 29.3% at 12M and 24.6% at 24M. The largest decline was observed with 100% RAP, where the strength dropped by 43.7% at 0M but improved to 36.5% at 12M and 31.1% at 24M as the treatment period progressed. The decline in compressive strength was likely caused due to the development of weaker bonds between the aggregate and the cement matrix. This reduction can be attributed to insufficient adhesion between the cement paste and RAP particles.

3.4. Flexural Strength

The flexural performance of PC mixes is an essential design factor that influences decisions on pavement slab thickness. As the amount of RAP replacement rose, the flexural strength of PC diminished, primarily because of the reduced interlocking between the cement and aggregate particles. Figure 5 shows the flexural strength across varying RAP replacement levels and treatment periods. For the control mix (0% RAP), the highest flexural strength was recorded at approximately 3.5 MPa across all treatment periods.

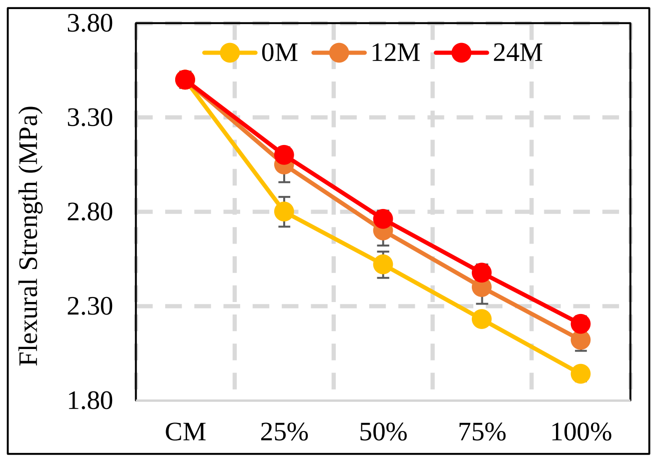
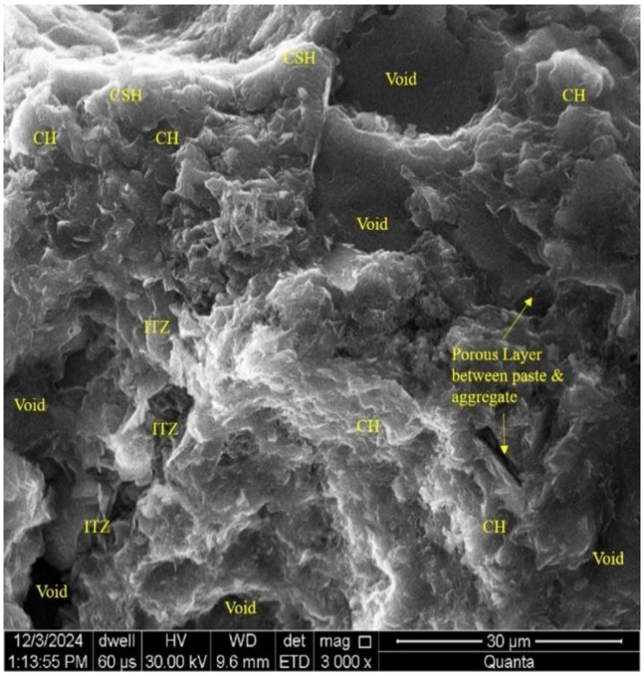


Fig. 5 Flexural strength of RAP mixes across various treatment periods (error bars indicate standard deviation)

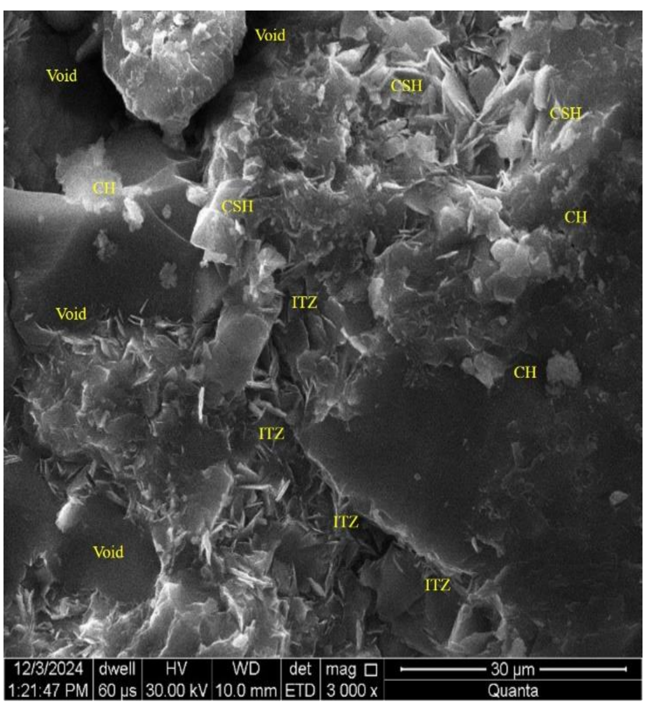
However, as the RAP content increases, the flexural strength declines. At 25% RAP, the flexural strength showed a 20% reduction compared with that of the control mix at 0 months. With extended treatment, the strength improved, reducing the loss to 12.8% at 12 months and to 11.4% at 24 months. The 100% RAP mix exhibited the lowest flexural strength, with a 44.6% reduction at 0 months, an improvement of 39.4% at 12 months and an improvement of 36.9% at 24 months. Additionally, porosity significantly influences flexural strength, as higher porosity in RAP mixes leads to a lower overall strength.

4. Microstructural Analysis

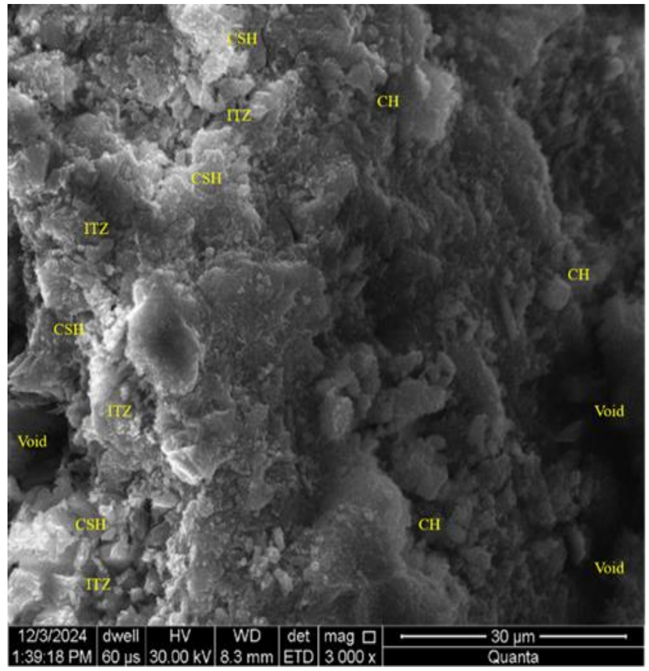
SEM analysis of Control Mix (CM), 0-month, 12-month, and 24-month specimens demonstrates the microstructural development of RAP-incorporated pervious concrete. The CM specimen displayed a compact ITZ, strong aggregate-matrix bonding, and well-formed C─S─H, ensuring high strength. In contrast, the 0-month RAP specimen showed a porous ITZ, increased CH, and lower C─S─H, weakening the bond and reducing strength. After 12 months, ITZ porosity declined, C─S─H formation improved, and bonding strengthened. By 24 months, the ITZ became highly dense, further enhancing its durability. These findings confirm that extended RAP treatment improves ITZ structure, minimizes porosity, and enhances hydration, contributing to greater strength and durability in pervious concrete.



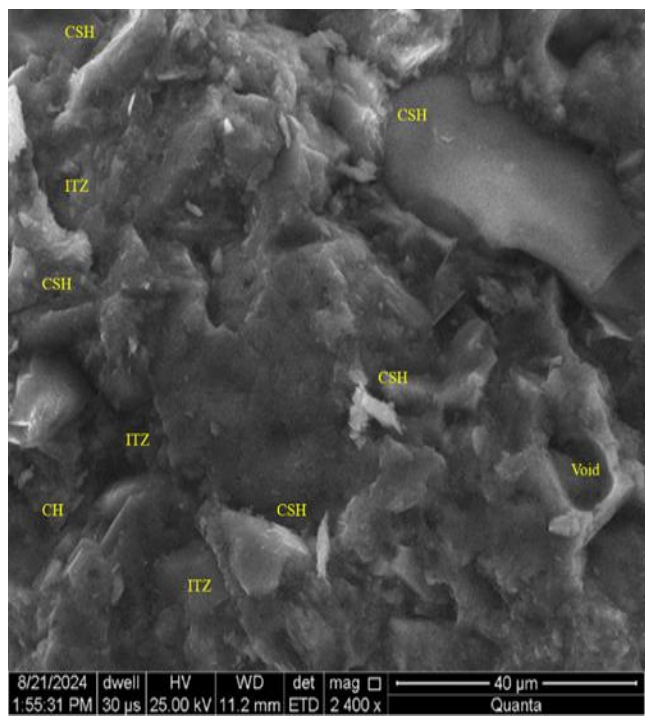
(a)



(b)



(c)



(d)

Fig. 6 Microstructural analysis of RAP-Modified pervious concrete Using SEM, (a) 0M, (b) 12M, (c) 24, and (d) CM.

5. Findings and Interpretation

This study highlights the substantial effect of RAP replacement and treatment of RAP regarding the effectiveness of pervious concrete mixes. The findings demonstrate how both the proportion of RAP and the duration of treatment influence key properties.

5.1. Density

As the RAP content increased, the density of PC mixes consistently decreased because of the diminished specific gravity of RAP and the asphalt layer, which reduced particle cohesion. Treatment of RAP, particularly at 12 and 24 months, led to a slight increase in density across all replacement levels. This enhancement resulted from the removal of the asphalt binder, which improved aggregate bonding and compaction.

5.2. Compressive and Flexural Strength

Higher RAP content resulted in a significant reduction in both compressive and flexural strengths was observed, with the most significant reduction occurring in the 100% RAP mix. Prolonged RAP treatment (12M and 24M) helped reduce strength loss. In the mix containing 100% RAP, compressive strength improved from a 43.7% reduction at 0M to 36.5% at 12M and further to 31.1% at 24M. Similarly, flexural strength exhibited significant enhancements with extended treatment durations.

5.3. Porosity and Permeability

Porosity and permeability rose with a rise in RAP content, alongside the highest values observed in the 100% RAP mix. The rise in permeability was linked to RAP's water-repellent nature, which facilitates improved water movement through the mixture. However, RAP treatment improved the mechanical properties, and its effect on porosity and permeability was less pronounced. These properties remained largely influenced by RAP content.

5.4. Balancing Hydraulic and Structural Performance

While higher RAP content improved permeability and porosity, it reduced strength, indicating that careful consideration is needed when determining RAP proportions to balance hydraulic efficiency and structural integrity. The extended treatment helped mitigate strength loss, making treated RAP a more viable option for achieving both structural and hydraulic performance in PC applications**.**

5.5. Microstructural Properties in Pervious Concrete

SEM analysis indicated that untreated RAP exhibited a porous ITZ, weak bonding, and low C-S-H content, resulting in reduced strength. However, with longer treatment durations, ITZ porosity decreased, C-S-H formation improved, and aggregate bonding strengthened, leading to better structural integrity and durability. By 24 months, the ITZ became more compact, further optimizing performance. These findings suggest that treated RAP is a viable and sustainable material for pervious concrete, offering both hydraulic efficiency and structural stability.

6. Conclusion

The study's findings indicate that although increasing RAP content in PC mixes improves permeability and supports sustainable construction, it also weakens the concrete's structural integrity. However, treating RAP over extended periods offers a promising way to mitigate the negative impacts on the strength properties, allowing for a more balanced performance between hydraulic and mechanical functionality.

This study underscores the importance of optimizing both the RAP content and treatment period to achieve sustainable and durable pervious concrete pavements. Integrating RAP into pervious concrete reduces the need for virgin aggregates, helping conserve natural resources and lower emissions linked to quarrying and transportation. The reuse of RAP also promotes sustainable waste management practices by reducing the volume of material directed to landfills. Economically, RAP holds significant cost-saving potential, as recycled aggregates are generally more affordable than newly sourced materials.

However, high RAP-content mixes may encounter durability challenges, particularly in environments with fluctuating temperatures and moisture levels, which could compromise long-term performance and increase maintenance requirements. While RAP offers notable environmental and economic advantages, careful consideration of treatment expenses and climatic durability constraints is essential to ensure its viability, sustainability, and durability in pervious concrete applications

6.1. Future Scope

Further research is essential to improve the workability of treated and untreated RAP in pervious concrete. Critical mechanical properties, including fatigue resistance, fracture, cracking, impact strength, shrinkage, and creep, require in-depth analysis to enhance durability. Effective RAP recycling also depends on the combined use of fine and coarse RAP, with a focus on treatment effects. Additionally, the nonlinear stress-strain behavior of RAP pervious concrete needs further study for precise modeling. Addressing these aspects will promote the sustainable and widespread application of treated RAP in pervious concrete pavements.

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