Evaluation of the durability performance of roller-compacted concrete incorporating recycled pavement materials

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Abstract:

Introduction/purpose: This research investigates the durability of roller-compacted concrete pavement (RCCP) incorporating reclaimed asphalt pavement (RAP) as a partial or full replacement for natural aggregates (NA). The primary objective is to assess the feasibility of using RAP in pavement concrete from both performance and sustainability perspectives.

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Methods: Concrete mixtures were prepared with four RAP substitution levels: 25%, 50%, 75%, and 100%. Durability tests were performed to evaluate the resistance of these mixes to acid and sulfate attacks. Additionally, microstructural analyses were conducted using scanning electron microscopy (SEM) and X-ray diffraction (XRD) to examine internal changes resulting from chemical exposure.

Results: The incorporation of RAP improved durability against acid and sulfate attacks, particularly at substitution levels up to 50%. Beyond this threshold, a slight decline in performance was observed, though it remained within acceptable limits. SEM images revealed a denser matrix and stronger bonding between the cement paste and RAP aggregates. XRD analysis confirmed the presence of stable hydration products, even after exposure to aggressive solutions.

Conclusion: The findings support the use of RAP as a viable and sustainable alternative to NA in RCCP. At optimal substitution levels, it enhances durability, contributes to environmental protection, reduces construction waste, and offers cost-effective solutions by utilizing recycled materials.

Key words: roller-compacted concrete, recycled aggregates pavement, microstructure, durability.

Introduction

Pavements form a critical component of global transportation infrastructure, whether constructed as rigid or flexible systems (Paglia et al, 2022; White et al, 2010). They are required to fulfill various performance criteria, including resistance to heavy traffic loads, durability under diverse climatic conditions, and adaptability to specific local environments and traffic patterns. As such, selecting the appropriate paving material is of paramount importance. Rigid pavements, generally composed of concrete, are valued for their strength and capacity to bear significant loads without undergoing deformation. In contrast, flexible pavements, primarily made from asphalt, are characterized by their ability to accommodate variations in traffic and temperature due to their elastic nature.

Both pavement types offer distinct advantages and face specific limitations that are influenced by local variables such as traffic volume, climate, and budgetary constraints (Santero, 2011). For instance, concrete pavements are particularly well-suited for high-traffic zones thanks to their long-term stability and abrasion resistance. However, they come with notable disadvantages, such as higher initial costs and more demanding maintenance routines, which can result in more frequent and costly repairs compared to asphalt alternatives (Bilodeau et al, 2012).

In contrast, flexible asphalt pavements, although more vulnerable to deterioration caused by temperature fluctuations and heavy traffic loads, are valued for their inherent flexibility. This trait allows them to better accommodate ground shifts and climate changes, offering a cost-effective solution in the short term. Nonetheless, their long-term durability is a concern, as they are more susceptible to cracking and the development of potholes (Modarres et al, 2014).

The RCCP has emerged as an innovative alternative that bridges the gap between rigid and flexible systems. Characterized by a low water-to-cement ratio and minimal water content, RCCP exhibits superior strength and exceptional durability (Boubekeur et al, 2024; Bílý et al, 2015). These properties make it particularly suitable for harsh climates and exposure to aggressive substances such as diesel (Poon et al, 2004). Additionally, RCCP’s simplified placement process and reduced dependence on heavy construction machinery can cut project costs by 10–30% compared to traditional concrete (Abut et al, 2022). An added environmental benefit is its compatibility with recycled materials, contributing to lower carbon emissions and more sustainable construction practices (Modarres et al, 2014).

Simultaneously, incorporating RAP into concrete has gained attention as a strategy for promoting circular economy principles in construction (Oss-Emer et al, 2024; Fakhri et al, 2017; Debbarma et al, 2019). The use of RAP allows for the recycling of previously discarded materials, thus reducing the demand for virgin aggregates and lessening the overall environmental footprint of infrastructure development (Aurangzeb et al, 2014). However, the integration of RAP is not without challenges. The residual bitumen present in RAP can hinder the bonding between the recycled aggregates and cement matrix, which may negatively impact the mechanical performance of the resulting concrete (Singh et al, 2020; Shi et al, 2021).

The growing emphasis on sustainability in road infrastructure has led to an increased interest in incorporating recycled materials like RAP. This shift, which gained momentum in Europe following the 1973-oil crisis (Bilodeau et al, 2012), reflects heightened environmental consciousness and the need to reduce industrial waste and carbon emissions (Modarres et al, 2014). Despite these efforts, technical challenges persist in integrating recycled materials into concrete mixes, necessitating further research to ensure both performance and long-term durability in pavement applications (Singh et al, 2018; Debbarma et al, 2021).

In this context, the present study investigates the potential of substituting NA with RAP in roller-compacted concrete (RCC) mixes. The main objective is to determine whether such replacements can be made without compromising mechanical strength and durability, while still meeting the functional requirements of pavement materials (Aghaeipour et al, 2020; Chaikaew et al, 2024). To this end, a series of RCCP mixes were developed by incrementally replacing natural coarse aggregates with RAP at levels of 25%, 50%, 75%, and 100%. Durability-related tests—including capillary water absorption, porosity, and resistance to acid and sulfate attacks—were conducted to assess material performance.

Concrete specimens were prepared following ASTM C267 (ASTM C267-20) and cured for 28 days. To replicate harsh environmental conditions, samples were exposed to 1% hydrochloric acid (HCl) and 3% sulfuric acid (H_2SO_4) solutions. Sulfate resistance was evaluated using 5% sodium sulfate (Na_2SO_4) and 5% magnesium sulfate ($MgSO_4$) solutions in accordance with ASTM C1012-04 (ASTM C1012-04). The tests aimed to evaluate the degradation behavior of the mixes under chemical and physical stress, including crack development and mechanical deterioration (Bassuoni et al, 2007).

The overarching goal of this study is to propose a sustainable alternative for constructing roller-compacted concrete pavements using recycled materials. By reducing reliance on virgin resources, this approach supports environmentally responsible construction practices and emphasizes the critical role of recycled materials in enhancing the durability of modern road infrastructure.

Experimental program

Material used

Aggregates

In this study, several types of aggregates sourced from different regions in Algeria were employed. The natural sand, with a particle size range of 0/4 mm, was collected from the Oued Ras area in the Chlef province. Additionally, two types of gravel were used, namely, 3/8 mm and 8/15 mm, both extracted from a quarry located in the Relizane province. These materials were chosen based on their local availability and favorable physical properties, which made them suitable for the experimental program.

The RAP used in the study was retrieved from a national highway in the Relizane region after 18 years of service.

Figure 1 – Milling of existing asphalt pavements

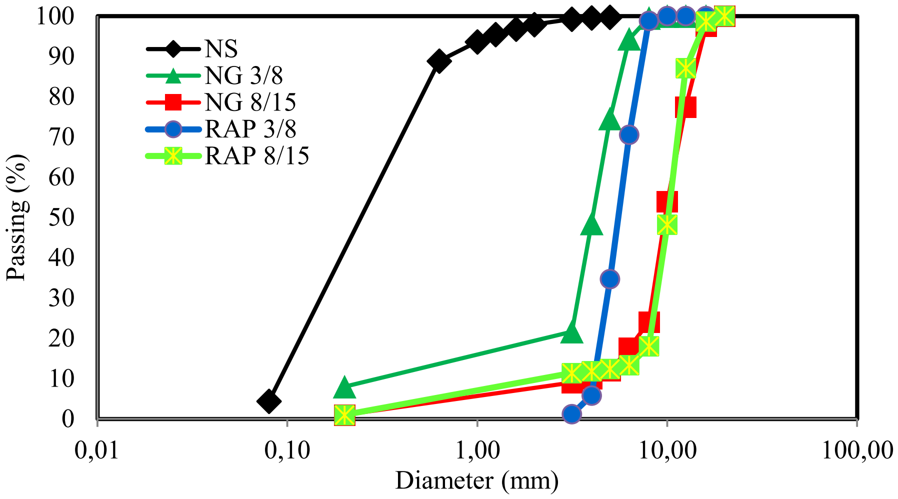

Figure 2 – Granulometric analysis of the aggregates used

The RAP material was carefully collected and then processed through crushing and sieving to obtain usable particles. One notable feature of the RAP aggregates is the presence of a hardened asphalt binder coating the coarse particles, which has a significant impact on their mechanical behavior and their interaction within concrete mixes.

Figure 2 presents the particle size distribution curves for the different aggregates, while Table 2 summarizes the physical properties of both NA and RAP. These data help in understanding the unique characteristics of each type of aggregate and facilitate a comparative analysis of their performance within the concrete mixtures studied.

Cement

The experimental program utilized a single type of cement: Portland cement classified as CEM II/C-M (P-L) 32.5 R. This is a composite cement that incorporates both limestone and pozzolanic materials, indicating a product containing 21-35% additives and having a relatively low clinker content. It was manufactured by the Oggaz cement plant, located in the Mascara province, and meets the requirements of Algerian standard NA 17092 as well as European standard EN 197-5. The key physical and mechanical properties of the cement, essential for analyzing the concrete mixtures, are presented in Table 1. This cement was chosen for its local availability and full compliance with current standards, ensuring the reliability and consistency of the materials used in the study.

Table 1 – Physicochemical and mineralogical characteristics of the cement used

Chemical composition (%)	
SiO_2	19.12
Al_2O_3	3.55
Fe_2O_3	3.45
CaO	58.7
MgO	1.65
SO_3	2.15
Free lime	—
Na_2O	0.12
K_2O	1.6
Loss of ignition	| 11 ± 1 |
Sulfate content (SO_3, %)	| 2.4 ± 0.5 |
Magnesium oxide content (MgO, %)	| Max 5% |
Mineralogical composition (%)	
C_2S	60.72
C_3S	12.15
C_3A	6.66
C_4AF	9.82

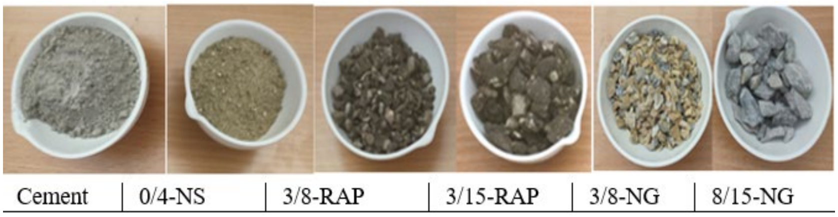

Figure 3 – The different types of aggregates used

Table 2 – Study of RCCP formulation

Materials (Kg/m^3)	**RCCP0**	**RCCP25**	**RCCP50**	**RCCP75**	**RCCP100**
Cement	250	250	250	250	250
W/C	0.576	0.472	0.49	0.472	0.552
Sand 0/4	631.7	631.7	631.7	631.7	631.7
Gravel 3/8 N	258.5	193,9	129,3	64,6	/
Gravel 8/18N	976.1	732,1	488,1	244	/
Gravel 3/8 RAP	/	64,6	129,3	193,9	258,5
Gravel 8/15 RAP	/	244	488,1	732,1	976,1
W_{opt}	6.9	5.58	5.8	5.57	6.61
Absorption rate of RAP 2.08% **Absorption rate of NA 0.97%**					

Testing methods

Mixing and compaction

Preparation of specimens

This study evaluates the influence of RAP on the performance of RCCP. Four specimen mixes were prepared with RAP replacements of 25%, 50%, 75%, and 100%, substituting NA in the 3/8 and 8/15 mm fractions. A 0% RAP mix served as the control. Cubic specimens (10×10×10 cm³) were produced by adjusting material proportions to assess fresh and hardened properties. Compaction was carried out using a vibrating hammer in accordance with NF EN 12697-32+A1, as shown in Figure 4.

Figure 4 – HILTI vibrating hammer

Mixing and curing process

The specimens were initially cured under wet-conditions at 20°C with 58% relative humidity, and demolded 24 hours after preparation. They were kept under these conditions until testing, after which they were transferred to their respective curing environments and maintained there until the performance testing.

Testing method

Acid and sulfate attack

Acid attack

Concrete surfaces are highly susceptible to physical and chemical deterioration, particularly when exposed to aggressive agents such as sulfate and chloride ions. Evaluating the resistance of these materials to such attacks is therefore essential. In this study, fifty concrete cubes measuring 100 mm were cast in accordance with ASTM C267 standards and cured for 28 days to assess their performance under acidic exposure.

To replicate aggressive environmental conditions in the laboratory, 3% solutions of hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) were prepared. For each RCCP formulation, two sets of ten specimens were submerged in the respective acid solutions.

Additionally, a third group of ten samples was used to monitor mass loss at 15-day intervals. The acid solutions were renewed every 30 days to ensure consistent concentration levels during the testing period. After 45 days of exposure, the specimens were removed, rinsed with tap water, and gently wiped with a cotton cloth before recording their surface-saturated mass. The percentage of mass loss was then calculated using appropriate formulas to evaluate the acid resistance of each RCCP mix.

Sulfate attack

Sulfate attack is another major factor contributing to the deterioration of concrete, particularly when exposed to environments rich in sulfate ions such as sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$). Several studies, including (Bassuoni et al, 2007), have investigated the impact of sulfate exposure on concrete, primarily focusing on two aspects: the physical degradation of the material and the quantification of that damage.

In this study, immersion tests were carried out following the procedures outlined in ASTM C267-20, where RCCP specimens were submerged for 45 days in solutions containing 5% Na_2SO_4 and 5% $MgSO_4$. The objective was to evaluate the influence of incorporating RAP on the sulfate resistance of the concrete.

Chemical analyses were conducted to assess the durability of the specimens and their ability to withstand sulfate-induced deterioration. The samples were carefully observed throughout the testing period to gain insight into the effects of sulfate solutions on both the mechanical and chemical behavior of concrete, particularly when partially or fully composed of recycled aggregates such as RAP (see Figure 5).

Figure 5 – Acid and sulfate attack test

Results and discussion

Durability tests

Sulfate and acid attacks

Figure 6 presents the mass variation of RCCP samples immersed in 5% Na_2SO_4 and $MgSO_4$ solutions. When RAP is incorporated at levels of 25%, 50%, 75%, and 100%, a mass gain is observed after 220 days of immersion in $MgSO_4$, compared to the reference concrete (RCCP0). Conversely, the samples immersed in Na_2SO_4 exhibit an approximate 65% increase in mass loss. Concrete exposed to $MgSO_4$ undergoes more pronounced expansion than that exposed to Na_2SO_4. This mass loss is largely due to the interconnected porosity in the cement matrix, which facilitates sulfate ion ingress and subsequent leaching of calcium compounds into the surrounding acidic solution (Singh et al, 2018; Debbarma et al, 2021; Aghaeipour et al, 2020; Chaikaew et al, 2024).

The results reveal a steady mass gain up to 15 days of immersion, followed by continued increase over time. This phenomenon is linked to the formation of expansive mineral phases such as gypsum and secondary ettringite, which accumulate, causing swelling and microcracking within the cement paste. When these crystals outgrow the available pore space, internal crystallization pressure builds up, leading to surface cracking. The sulfate attack is driven by chemical reactions between sulfate ions in the solution and tricalcium aluminate (C_3A) in the cement, forming calcium sulfate hydrates.

Among the mixtures tested, RCCP0 (control) exhibits the smallest mass gain (0.5%), while RCCP100 shows the highest (3%). Additionally, the mass loss of RCCP50 is about 50% lower than that of RCCP100 in the most aggressive exposure conditions.

Overall, the findings suggest that replacing 50% of natural coarse aggregates with RAP in RCCP offers promising performance for sidewalk applications in environments containing sulfates and chlorides. Notably, RCCP25 and RCCP50 experienced only 4% and 2% additional mass loss, respectively, compared to the control under sulfate exposure—supporting their suitability for pavement construction near sulfate-rich areas.

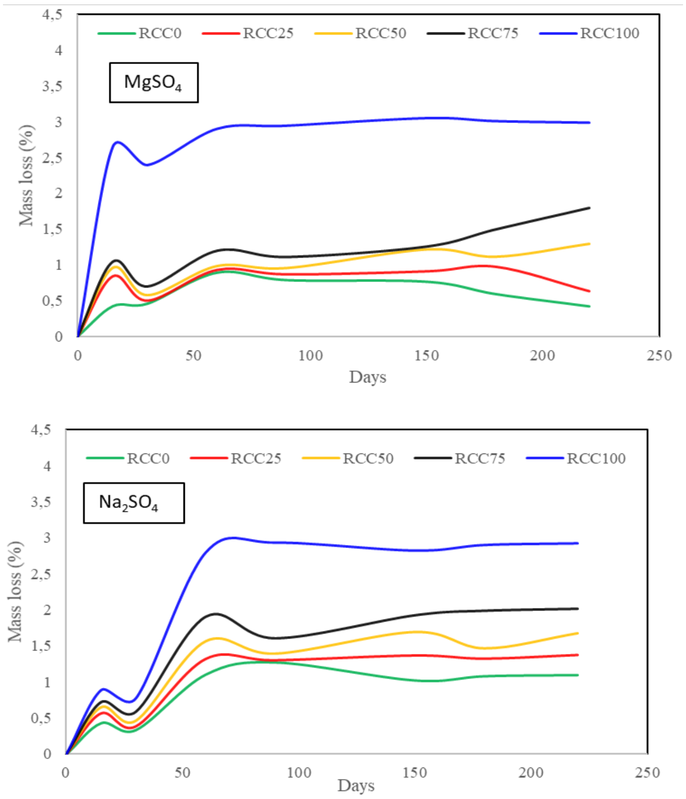

Figure 6 – The mass loss of (RCCP) immersed in both $MgSO_4$ *and* Na_2SO_4

Figure 7 illustrates the mass loss experienced by RCCP with varying RAP substitution levels (25%, 50%, 75%, and 100%) when exposed to hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) over a period of 0 to 220 days. These data are vital for evaluating the acid resistance of the concrete, as such environments are known to accelerate structural degradation.

Under HCl exposure, the reference mix (0% RAP) demonstrates a gradual increase in mass loss, reaching 1.62% after 220 days. The rate of mass loss is more pronounced in the early stages (between 15 and 60 days) before stabilizing. As the RAP content increases, the degree of mass loss becomes more significant. For instance, the mix with 100% RAP shows a mass loss of 2.83%, nearly twice that of the control. This trend suggests that concretes with higher RAP levels deteriorate faster in acidic environments, likely due to greater porosity and permeability. The residual bitumen on RAP aggregates may facilitate acid and water infiltration, accelerating degradation (Singh et al, 2018).

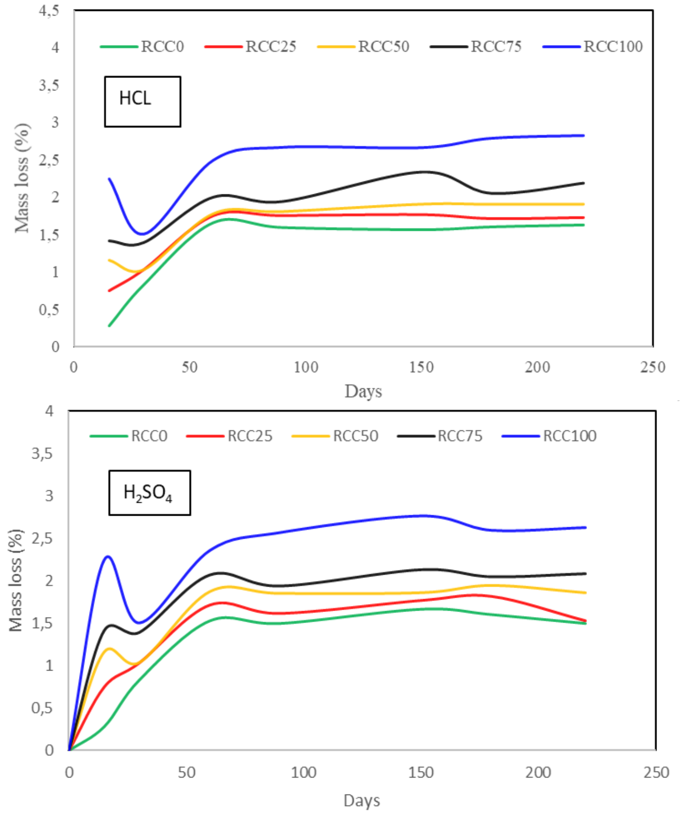

Figure 7 – Comparison of measured and calculated weight loss mortars immersed in H_2SO_4 and HCL solutions

The behavior of concrete under sulfuric acid (H_2SO_4) exposure mirrors the trends observed with hydrochloric acid (HCl). The reference mix (0% RAP) exhibits a gradual increase in mass loss, reaching approximately 1.49% after 220 days. The most significant loss occurs during the early phase (between 15 and 60 days), after which the values begin to level off. As the percentage of RAP increases, mass loss becomes more pronounced. Specifically, the mix containing 100% RAP records a mass loss of 2.63% at 220 days. This trend confirms that higher RAP content leads to greater deterioration, likely due to the aggressive action of sulfuric acid on the cement matrix. The formation of expansive compounds such as gypsum and secondary ettringite byproducts of the acid's reaction with calcium-bearing phases can induce internal stresses, causing cracks and further degradation of the concrete structure (Rahman et al, 2021).

Exposure to both HCl and H_2SO_4 subjects the concrete to intense chemical reactions that progressively compromise its integrity. The correlation between increased RAP content and higher mass loss highlights the critical role of porosity in acid resistance. As RAP content rises, so does the permeability of the concrete, making it more susceptible to acid penetration and subsequent chemical attack (Debieb et al, 2010).

These results support previous research showing that although RAP offers environmental advantages, its incorporation into concrete can compromise durability in acidic environments. The high porosity of RAP and the nature of the residual bitumen can accelerate degradation processes, reducing the long-term performance of concrete under chemically aggressive conditions (Masi et al, 2022).

The data illustrated in Figure 6 show the mass loss experienced by RCCP containing varying proportions of RAP (25%, 50%, 75%, and 100%) after immersion in sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) solutions over a period of 0 to 220 days. These experiments were designed to evaluate the sulfate resistance of the concrete, an essential factor in environments where high sulfate concentrations can accelerate concrete deterioration.

For sodium sulfate (Na_2SO_4) exposure, the reference mixture with 0% RAP shows a steady increase in mass loss, reaching approximately 1.09% by day 220. The greatest mass loss occurs in the early stages (15 to 30 days), after which the values tend to plateau, likely due to the formation of expansive compounds such as ettringite. However, as the RAP content in the concrete increases, so does the mass loss. For instance, the 25% RAP mix records a mass loss of 1.37%, while the 100% RAP mix shows a significant increase to 2.93% after 220 days. This trend suggests that higher RAP content makes the concrete more vulnerable to sulfate attack. The porous structure of RAP enhances the permeability of the concrete, facilitating the ingress of sulfate ions and promoting the chemical reactions responsible for the formation of expansive products (Uygunoğlu et al, 2024).

In the case of magnesium sulfate ($MgSO_4$), mass loss is generally more pronounced than in the Na_2SO_4 condition. This is attributed to the more aggressive reactions between $MgSO_4$ and calcium aluminates in the cement paste, which result in the formation of expansive minerals such as gypsum and secondary ettringite. These reactions cause internal stress, leading to microcracking and further degradation. The control mix (0% RAP) shows a mass loss of about 0.42% after 220 days, while the 100% RAP mix experiences a significantly higher mass loss of 3%. This outcome underscores the increased susceptibility of RAP-containing concretes to magnesium sulfate attack. The higher porosity and heterogeneity of RAP allow deeper penetration of sulfate ions, amplifying the damage caused by these chemical reactions (Shi et al, 2018).

The observed increase in mass loss with higher levels of RAP substitution suggests that concrete becomes more vulnerable to sulfate-induced degradation as the RAP content rises. This trend aligns with previous research indicating that incorporating RAP modifies the concrete's porosity and chemical makeup, increasing its susceptibility to chemical attacks particularly in environments rich in sulfate ions (Debbarma et al, 2019). The inherent porosity of RAP facilitates deeper ion penetration, accelerating sulfate reactions and promoting expansion and cracking within the concrete matrix. While using RAP in concrete offers clear environmental advantages, these findings emphasize the importance of carefully optimizing RAP content in applications exposed to sulfates. Strategies such as limiting RAP dosage or integrating supplementary cementitious materials (SCMs) including fly ash, slag, or silica fume can significantly enhance sulfate resistance. These SCMs contribute to a denser microstructure, reduce overall porosity, and mitigate the formation of expansive products that cause degradation and mass loss (Bashkoul et al, 2018). Additionally, a thorough analysis of the chemical characteristics and physical properties of RAP could support the development of tailored mix designs to improve the long-term durability of concrete in sulfate-rich environments.

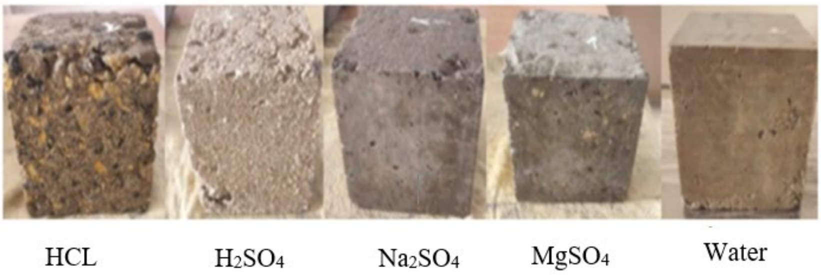

Figure 8 – State of RCCP 50% in various aggressive environments

Microstructure of RCCPs preserved in attack solutions

Scanning Electron Microscope (SEM) analyses of RCC samples incorporating 50% of RAP aggregates reveal notable differences in microstructural behavior depending on the curing environment. Under water-based conditions, the concrete displays a well-developed and hydrated matrix, with a clearly defined interfacial transition zone (ITZ) between the recycled aggregates and the new cement paste. The porosity remains moderate, and no significant deterioration is observed—indicating effective cement hydration and stable structural integrity.

These findings are consistent with previous studies, such as (Rout et al, 2023), who demonstrated the feasibility of using RAP in rigid pavement applications and reported a good bond between recycled aggregates and the cement matrix. Likewise, Fakhri et al. (2017) found that RCC mixtures containing RAP, especially when combined with crumb rubber, can achieve adequate mechanical performance, provided the mix design is carefully controlled.

However, when subjected to aggressive environments, the concrete exhibits marked microstructural degradation. In the presence of magnesium sulfate, there is evident dissolution of portlandite and deterioration of calcium silicate hydrate (C-S-H) gel, along with the formation of secondary products like gypsum and magnesium silicate hydrate (M-S-H). These changes are accompanied by microcracking and increased porosity. Similar degradation patterns were reported by Singh et al. (2017), who emphasized the impact of chemical exposure on the durability of RAP-containing concrete, particularly when mineral admixtures are involved. Exposure to hydrochloric acid (HCl) further compromises the concrete's microstructure. Major hydration products such as portlandite and C-S-H gel are significantly diminished or completely dissolved, the ITZ becomes critically weakened, and calcium chloride deposits are observed—collectively undermining the material's long-term durability. Abdel-Mohti et al. (2016) reached comparable conclusions, noting that the performance of self-consolidating concrete with RAP is strongly influenced by binder composition and environmental exposure conditions.

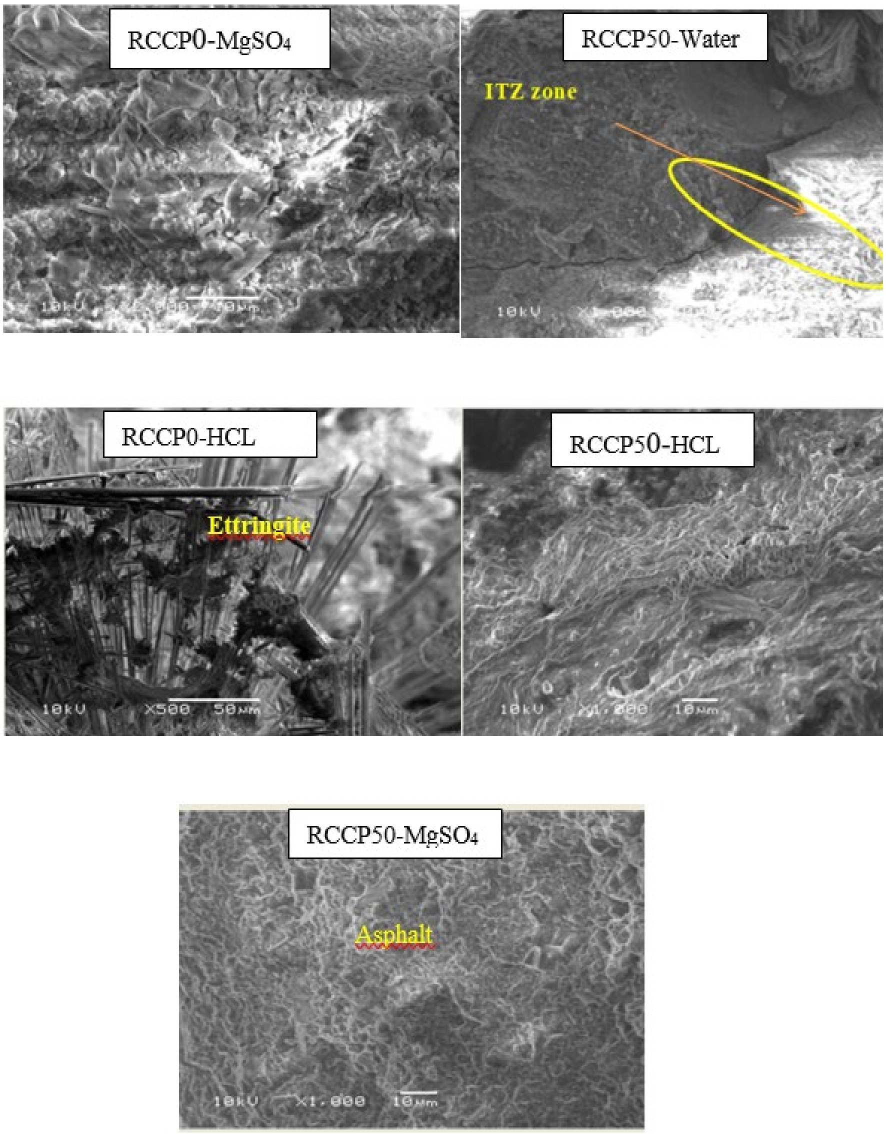

Figure 9 – Microstructure of RCCs preserved in acid and sulfate solutions

Overall, the results of this study are in line with existing literature and reinforce the idea that while RAP is a viable and sustainable alternative in concrete production, its performance is highly dependent on environmental factors and mix design parameters. Proper evaluation of exposure conditions and material compatibility is essential to ensure the durability and reliability of recycled concrete in practical applications.

X-ray diffraction (XRD)

It is essential to analyze the XRD spectrum of a RCC sample containing 50% recycled asphalt concrete aggregates and preserved in a sodium sulfate solution. The interpretation should focus on the mineral phases formed, the possible disappearance of others, and the influence of sodium sulfate on the concrete's microstructure and composition. Accurately identifying each diffraction peak and noting the presence or absence of specific phases is crucial. The XRD analysis of an RCC sample with 50% recycled asphalt aggregates preserved in a magnesium sulfate solution reveals degradation of key cementitious phases. Portlandite peaks are significantly weakened or disappear entirely, indicating its dissolution due to the aggressive attack. Gypsum peaks appear as a result of chemical reactions, and the C-S-H gel is altered—likely transforming into a less stable magnesium silicate hydrate (M-S-H) phase. Inert phases, such as quartz, remain unchanged. Overall, magnesium sulfate exposure leads to microstructural deterioration, compromising the strength and durability of the concrete.

Similarly, the XRD analysis of RCC with 50% recycled asphalt concrete aggregates preserved in a sodium sulfate solution reveals important chemical changes. This environment promotes the formation of gypsum ($CaSO_4 \cdot 2H_2O$) and ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$), which are characteristic products of sulfate attack and can cause internal expansion and cracking. Peaks for quartz, Portlandite, C-S-H, gypsum, ettringite, and possibly calcite (due to carbonation) are expected. The reduction in portlandite peak intensity confirms its reaction with sodium sulfate and the consequent formation of new expansive phases. The persistence of quartz peaks is attributed to the inert nature of both natural and recycled aggregates.

These results are consistent with findings from Rahman and Khattak (2021) and Rahman et al. (2021), who reported similar microstructural degradation in concrete containing both RCA and RAP. Their study demonstrated that sulfate attacks result in the formation of ettringite and gypsum, negatively affecting mechanical performance and long-term durability.

In the case of HCl exposure, the XRD spectrum of RCC with 50% RAP shows severe microstructural damage. Portlandite and C-S-H are heavily dissolved or altered, significantly weakening the matrix. Calcium chloride ($CaCl_2$) may form as a reaction product, although it may not be easily detected due to its solubility. Quartz remains unaffected. Overall, hydrochloric acid exposure leads to deterioration of the cement matrix and reduced durability.

Likewise, sulfuric acid exposure causes extensive degradation. The XRD analysis reveals dissolution of portlandite, formation of gypsum, and transformation of aluminate phases into secondary ettringite. These reactions generate internal stresses, leading to cracking and mechanical failure. Despite these transformations, quartz remains stable, serving as a reference. Sulfuric acid exposure severely compromises both the strength and durability of the concrete.

Conversely, the XRD spectrum of RCC with 50% RAP preserved in water indicates a healthy hydration process. Well-defined peaks of C-S-H and portlandite suggest complete hydration, while quartz remains stable. Water curing enhances the crystallinity of hydration products and strengthens the matrix. The presence of recycled aggregates does not significantly disrupt the hydration, although it may slightly broaden the peaks due to microstructural variability. These findings support the conclusion that water curing promotes robust microstructure development even with the integration of 50% RAP, aligning with the results of Morales et al. (2020), who emphasized the benefits of water preservation in enhancing hydration in recycled aggregate concrete.

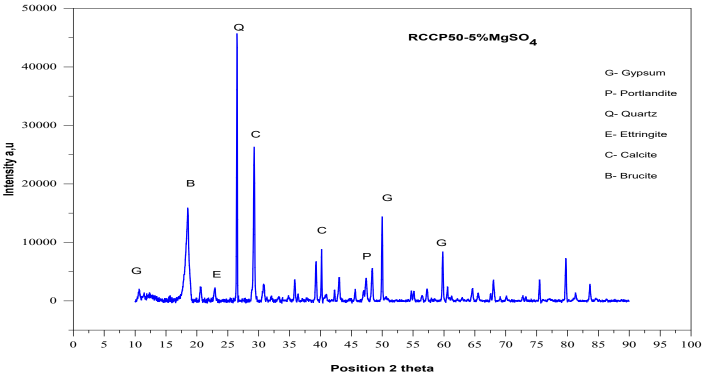

Figure 10 – RCCP50-MgSO4

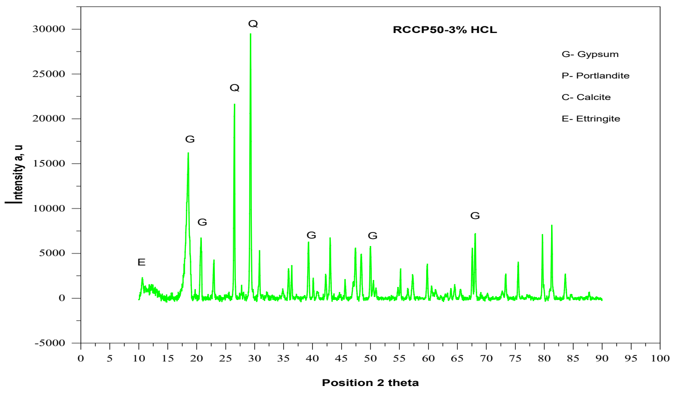

Figure 11 – RCCP50-HCL

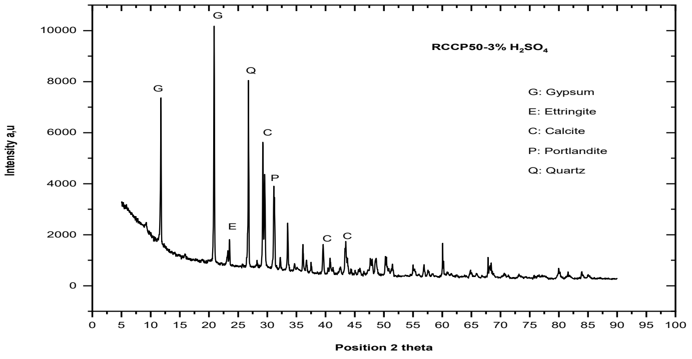

Figure 12 – RCCP50-H_2SO_4

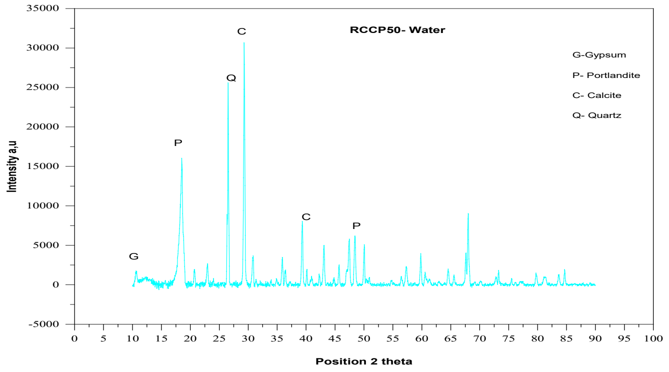

Figure 13 – RCCP50-Water

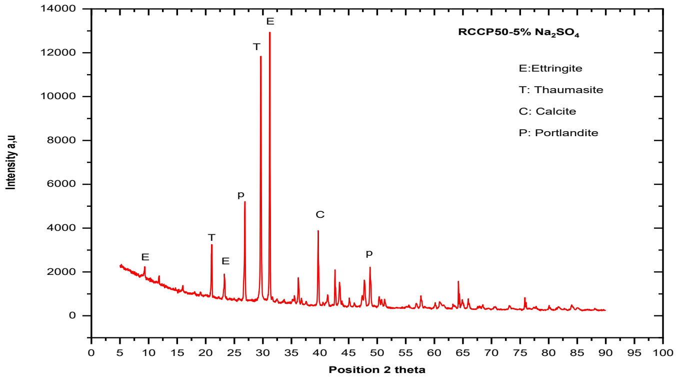

Figure 14 – RCCP50-Na_2SO_4

Conclusion

Incorporating RAP into RCCP influences its properties in significant ways, with effects that can be either advantageous or problematic depending on the RAP proportion and curing conditions.

The resistance of RCCP containing RAP to chemical attacks, such as sulfate (Na_2SO_4) and acid (HCl and H_2SO_4) attacks, is lower compared to conventional RCCP. This is due to the increased porosity, which allows aggressive ions to penetrate more easily. However, mixes with lower RAP content (less than 50%) perform better than those with higher RAP content, indicating that some degree of RAP substitution can still yield acceptable chemical resistance. Proper curing and mix optimization can further enhance the performance of RAP-based RCCP in hard environments.

The overall effect of RAP on RCCP performance represents a trade-off between the environmental benefits of using recycled materials and durability aspects, such as resistance to chemical attacks. However, with proper curing techniques, especially at elevated temperatures, the negative impacts of RAP on the durability of RCCP can be mitigated. Additionally, RAP provides a sustainable solution by reducing the need for virgin aggregates, contributing to more eco-friendly construction practices.

The study analyzes the effects of different preservation environments on the microstructure of roller-compacted concrete containing 50% recycled asphaltconcrete aggregates using XRD and SEM techniques. Water curing enhanceshydration and maintains a dense, stable microstructure. In contrast, exposure tosodium and magnesium sulfate leads to the dissolution of key hydrates (portlandite and C-S-H) and the formation of gypsum, ettringite, or M-S-H,indicating sulfate attack. HCl exposure causes severe degradation, including microcracking and increased porosity. Overall, aggressive environments deteriorate the concrete's durability, while water curing improves it.

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Procena trajnosti valjanog betona sa recikliranim materijalima iz kolovoznih konstrukcija

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Sažetak:

Uvod/cilj: U ovom *istraživanju se ispituje trajnost valjanog betona za kolovoze (eng. RCCP) sa dodatkom recikliranog asfaltnog betona (eng. RAP) kao delimične ili potpune zamene za prirodne agregate (eng. NA). Osnovni cilj je procena mogućnosti primene recikliranog asfaltnog betona u betonu za kolovozne konstrukcije sa stanovišta performansi i održivosti.*

Metode: Betonske mešavine su pripremljene sa četiri nivoa zamene recikliranog asfaltnog betona: 0%, 25%, 50%, 75% u 100%. Vrše se ispitivanja izdržljivosti, a sprovedene su i mikrostrukturne analize upotrebom skenirajuće elektronske mikroskopije (eng. SEM) i rendgenske difrakcije (eng. XRD) u cilju ispitivanja unutrašnjih promena pri hemijskom napadu.

Rezultati: Ugradnja recikliranog asfaltnog betona poboljšala je otpornost na dejstvo kiselina i sulfata, posebno pri nivoima zamene do 50%. Iznad ove granice uočen je blagi pad performansi, iako su one ostale u prihvatljivim okvirima. Snimci skenirajuće elektronske mikroskopije pokazali su gušću matricu i bolje prianjanje između cementne paste i RAP agregata. Rendgenska difrakcija potvrdila je prisustvo stabilnih hidratacionih produkata i nakon izlaganja agresivnim rastvorima.

Zaključak: Rezultati podržavaju upotrebu recikliranog asfaltnog betona kao održive i izvodljive alternative prirodnim agregatima u valjanom betonu za kolovoze. Pri optimalnim nivoima zamene, reciklirani asfaltni beton poboljšava trajnost, doprinosi zaštiti životne sredine, smanjuje građevinski otpad i omogućava ekonomski isplativa rešenja kroz upotrebu recikliranih materijala.

Ključne reči: valjani beton, kolovoz od recikliranog agregata, mikrostruktura, trajnost.

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