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Analyzing the Environmental Impact of Recycled Concrete Aggregates for Road Base Construction in Mauritius

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Abstract: The depletion of natural aggregates and the increasing volume of construction and demolition (C&D) waste demand innovative solutions for sustainable construction practices. This study evaluates the feasibility and environmental benefits of incorporating Recycled Concrete Aggregates (RCA) into road base construction in Mauritius. Laboratory analyses were conducted on seven design mixes of RCA blended with conventional crushed aggregates (CRU), assessing key properties such as compaction, durability, and compliance with Road Development Authority (RDA) standards. The optimal mix of 30-40% RCA with 60-70% CRU demonstrated reliable performance for high-traffic roads while achieving a 3.8-6.3% reduction in energy consumption and a 1.9-3.5% decrease in CO2 emissions. Additionally, the research highlights the scalability of RCA in addressing natural resource scarcity and reducing landfill contributions in small island states. A lifecycle assessment, supported by SEVE software, quantified the environmental gains, emphasizing reduced energy demands and minimized carbon footprints compared to traditional practices. The study underscores the role of policy, industry investment, and standardized guidelines in mainstreaming RCA adoption in infrastructure projects. By combining environmental stewardship with technical reliability, this work advances sustainable development goals and sets a precedent for integrating recycled materials into construction sectors worldwide. This research offers a transformative approach to road construction, balancing performance and sustainability while contributing to a circular economy in regions with limited aggregate resources.

Keywords: Recycled Concrete Aggregates; Road Base; Circular Economy, Life Cycle Assessment

1. Introduction

The rapid growth of the global construction sector has resulted in a twofold challenge: the depletion of natural aggregates and the escalating accumulation of construction and demolition (C&D) waste, which exceeds 10 billion tonnes annually. Small island states like Mauritius face heightened difficulties due to limited natural aggregate resources and land constraints for waste disposal. This scenario underscores the urgency for innovative and sustainable practices in construction material sourcing.

Recycled Concrete Aggregates (RCA) derived from C&D waste present an environmentally and economically viable alternative to conventional crushed aggregates (CRU). Globally, RCA has shown promising potential in road construction, particularly in base and sub-base layers. Research from countries like the United States, Australia, and parts of Europe highlights RCA's ability to match or exceed performance standards under specific conditions. Furthermore, RCA offers significant environmental benefits, including reduced energy consumption and carbon emissions, and helps divert waste from landfills. However, challenges such as variability in RCA quality, reduced mechanical strength, and higher water absorption persist, leading to debates about its reliability in high-demand applications.

In Mauritius, the adoption of RCA remains minimal despite its potential to alleviate the reliance on imported aggregates and to address C&D waste management challenges. Factors hindering its adoption include a lack of established standards, limited awareness, and insufficient validation of RCA's performance under local climatic and traffic conditions. This gap necessitates targeted research to establish RCA as a sustainable option for infrastructure development in Mauritius.

This study evaluates the technical and environmental feasibility of integrating RCA into road base construction in Mauritius. Through laboratory analyses and lifecycle environmental assessments, the research identifies optimal RCA-CRU mixes and quantifies their benefits. The findings demonstrate that blends containing 30–40% RCA meet performance requirements while reducing carbon emissions and energy consumption, offering a practical solution for sustainable infrastructure development. These insights contribute to bridging the gap between environmental stewardship and technical reliability in the construction industry.

2. Materials and Methods

2.1 Materials

The primary materials used in this study were Recycled Concrete Aggregates (RCA) sourced from construction and demolition (C&D) waste processed by Gamma Materials Ltd., and Conventional Crushed Aggregates (CRU) derived from basalt quarries in Mauritius. RCA underwent crushing, screening, and grading to meet specifications for road base construction, while CRU followed standard industry preparation protocols. All materials adhered to Road Development Authority (RDA) standards for gradation and quality.

2.2 Design of Mix Proportion

Seven design mixes were prepared, varying RCA content from 10% to 70% in 10% increments, with the remainder comprising CRU. A control mix of 100% CRU was included for comparative purposes. The proportions were calculated by weight, and the incremental design facilitated systematic evaluation of mechanical and environmental performance.

2.3 Laboratory Testing

The following tests were performed under controlled conditions to evaluate material properties and ensure compliance with engineering standards for road base applications:

1. **Sieve Analysis**: Used to assess particle size distribution and validate gradation against RDA specifications.
2. **Proctor Compaction Test**: Determined the optimum moisture content (OMC) and maximum dry density (MDD) for each mix.
3. **Flakiness Index**: Measured particle shape to evaluate its impact on compaction.
4. **Los Angeles Abrasion Test**: Quantified aggregate durability under mechanical stress, with results reported as percentage wear.

Testing procedures followed ASTM D1241 and EN 13242 standards. Each test was performed in triplicate to ensure repeatability and accuracy of results.

2.4 Environmental Assessment

The environmental impact of each mix was evaluated using lifecycle analysis tools embedded in SEVE software. The assessment calculated carbon emissions and energy consumption for a hypothetical 1 km road segment. The analysis considered all lifecycle stages, including raw material extraction, processing, transportation, and construction.

2.5 Case Study Validation; Flic en Flac

A case study was conducted on the Flic en Flac bypass road in Mauritius to validate laboratory findings under real-world conditions. The RCA-CRU mixes were evaluated for compaction, load-bearing capacity, and durability in situ. Performance results were compared against the control mix (100% CRU) to determine practical applicability and environmental benefits.

2.6 Data Analysis and Statistical Validation

The data collected from the laboratory tests and case study were analyzed to identify the optimal RCA-CRU mix ratio that meets RDA standards while offering significant environmental benefits. Descriptive statistics were used to summarize key material properties such as gradation, density, and strength, while statistical comparison methods were employed to evaluate performance variations across different mix ratios. Graphical tools, such as histograms and pie charts, were utilized to visualize trends and relationships for clarity and precision. By integrating both technical and environmental perspectives, this methodological approach ensures robust conclusions on the potential of RCA in road base construction in Mauritius.

3. Results

3.1 Particle Size Distribution and Grading Distribution

The particle size distribution of the RCA-CRU mixes was assessed through sieve analysis. All mixes exhibited gradation curves that fell within the upper and lower limits prescribed by the Road Development Authority (RDA). This indicates that the RCA inclusion, even at higher proportions, does not compromise compliance with grading requirements for road base materials. Mixes containing 30% to 50% RCA demonstrated optimal particle size distribution, aligning closely with the ideal gradation curve for enhanced compaction and load-bearing capacity. Figure 1 presents the particle size distribution for all seven mixes, illustrating that RCA blends up to 70% maintained a consistent gradation suitable for road base construction.

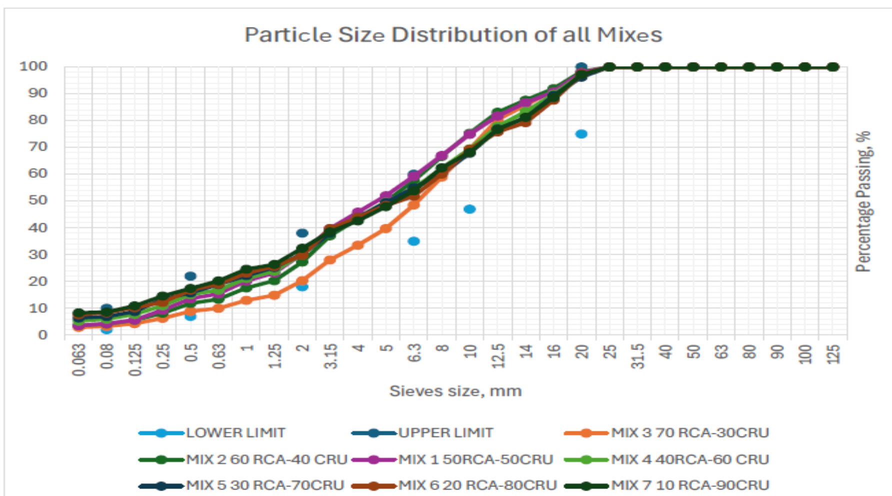

Figure 1. Particle size Distribution of RCA-CRU Mixes

3.2 Compaction Characteristics

The Proctor compaction test revealed a progressive increase in maximum dry density (MDD) as the proportion of CRU increased. Mixes with 10% RCA and 90% CRU achieved the highest MDD values, indicative of superior compaction properties. However, blends with 30% to 40% RCA also displayed satisfactory MDD, meeting the RDA standards for road base construction. Optimum moisture content (OMC) was consistent across all mixes, confirming that RCA inclusion has minimal impact on water requirements during compaction. Figure 2 provides a comparison of the MDD and optimum moisture content (OMC) values for each mix.

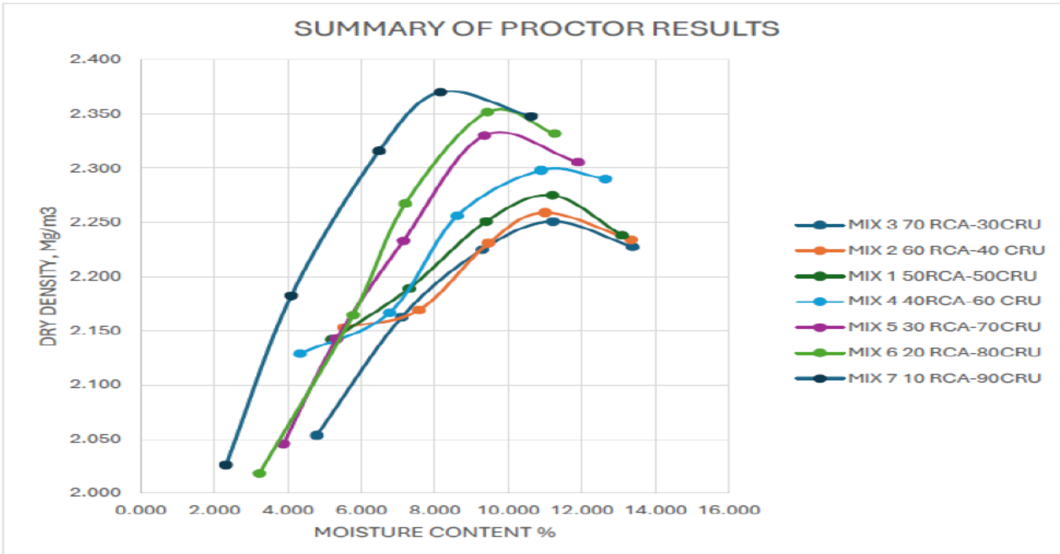

Figure 2. Protor Compaction Test Results for RCA-CRU Mixes

3.3 Durability, Abrasion Resistance. Sand Equivalent and Flakiness Index

Los Angeles abrasion tests highlighted the durability of the RCA-CRU blends. While mixes with higher RCA content exhibited marginally higher abrasion values, all blends remained within acceptable limits. The 30% RCA and 70% CRU blend achieved an optimal balance, with abrasion values indicating sufficient resistance to wear and mechanical degradation. This makes it suitable for moderate to high-traffic road bases. Table 1 illustrates the abrasion values, sand equivalent and flakiness index for all mixes

Table 1. Los Angeles Abrasion Test Results, Sand Equivalent and Flakiness index for RCA-CRU Mixes Test Results

SAMPLE/MIX	PROCTOR		LA ABRASION TEST		SAND EQUIVALENT		FLAKINESS (%)		GRADING
	MDD	OMC	LA ABRASION VALUE (%)	*REMARKS*	SE VALUE	*REMARKS*	FI VALUE (%)	*REMARKS*	
MIX 3 70 RCA-30CRU	2.252	11.6	31	NOT VALID	81	VALID	1	VALID	VALID
MIX 2 60 RCA-40 CRU	2.261	11.4	29	VALID BUT LIMIT	79	VALID	1	VALID	VALID
MIX 1 50RCA-50CRU	2.275	11.2	27	VALID	78	VALID	1	VALID	VALID
MIX 4 40RCA-60 CRU	2.298	10.8	26	VALID	76	VALID	1	VALID	VALID
MIX 5 30 RCA-70CRU	2.316	10.5	24	VALID	74	VALID	1	VALID	VALID
MIX 6 20 RCA-80CRU	2.351	9.8	23	VALID	73	VALID	1	VALID	VALID
MIX 7 10 RCA-90CRU	2.379	9.1	21	VALID	71	VALID	1	VALID	VALID

3.4 Environmental Impact; Carbon Emissions

The environmental assessment demonstrated that substituting CRU with RCA significantly reduces CO2 emissions. For a 1 km road segment, mixes containing 30% RCA and 70% CRU as presented in Figure 3 showed a 3.5% reduction in total CO2 emissions compared to 100% CRU. This reduction stems primarily from the decreased need for virgin aggregate extraction and processing, highlighting RCA's potential for mitigating the environmental footprint of road construction projects in Mauritius.

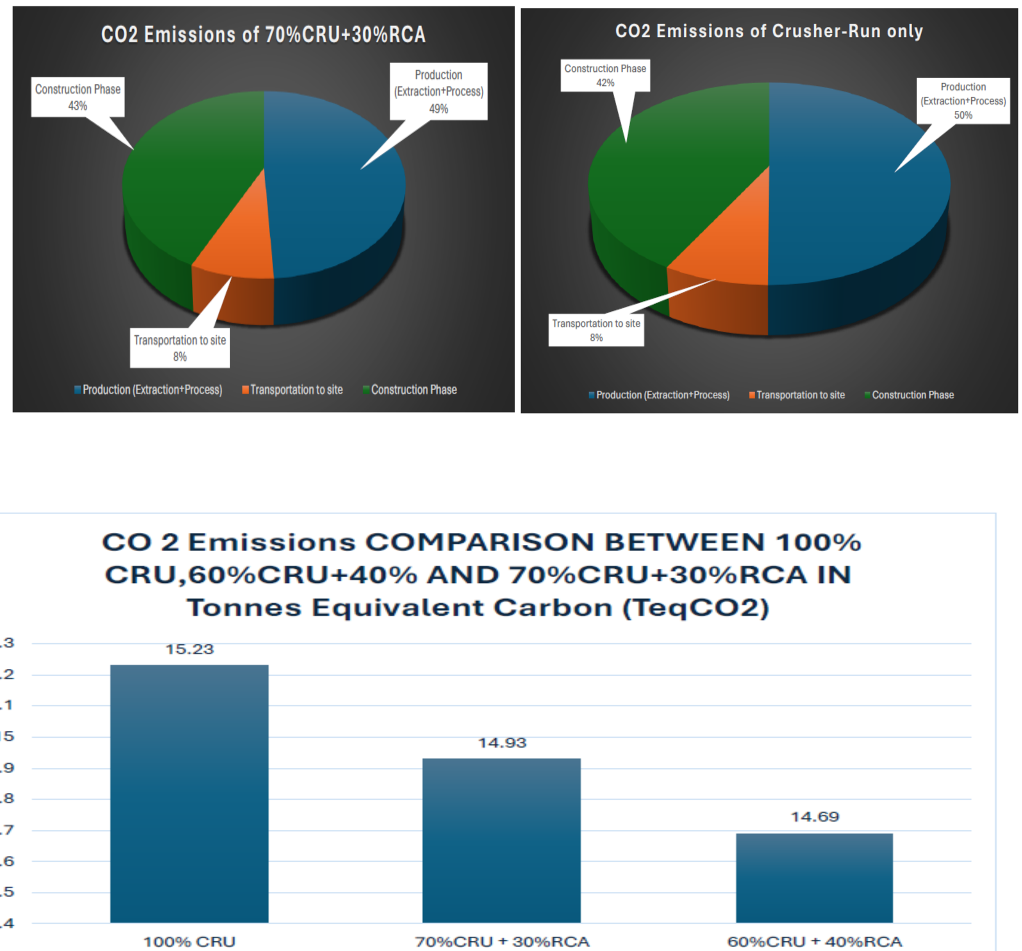

Figure 3. CO2 Emissions Comparison for RCA-CRU Mixes

3.5 Environmental Impact

Energy consumption analysis revealed similar trends, as shown in figure 4 with mixes containing 30% to 40% RCA achieving a 6.3% reduction in total energy use. The bulk of the savings originated during the material production phase, as RCA processing requires less energy than quarrying and crushing virgin aggregates. This underscores the viability of RCA as an energy-efficient alternative for road base materials.

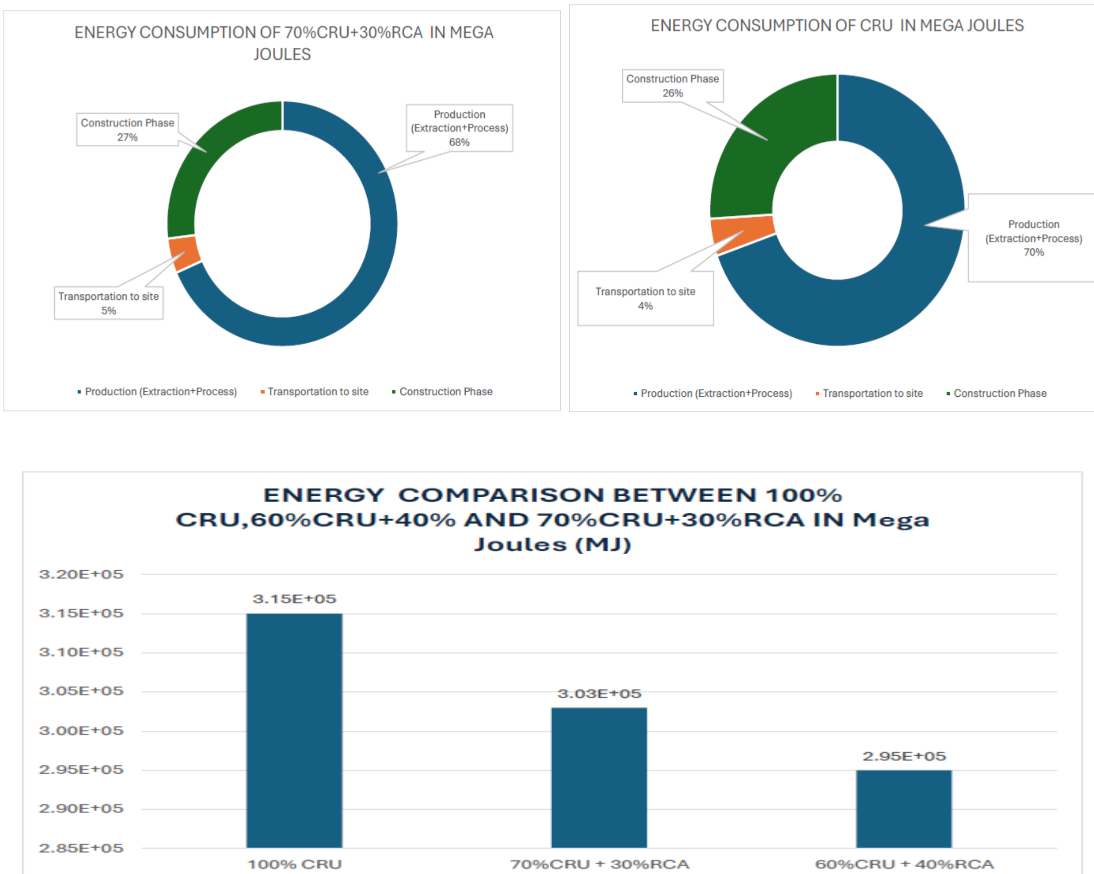

Figure 4. Energy Consumption and Comparison for RCA-CRU Mixes

3.6 Environmental Impact ; Energy Consumption

The findings from the laboratory tests were corroborated by the case study on the Flic en Flac bypass. The construction phase demonstrated that the 30% RCA blend maintained structural integrity under practical conditions while reducing environmental impact. The performance of this mix under real-world loading conditions affirmed its suitability for road base construction.

3.7 Summary of Optimal Mix Proportion

The analysis identified the 30% to 40% RCA blend as the most balanced option, delivering satisfactory mechanical performance while achieving significant environmental benefits. For heavily trafficked roads, lower RCA content, such as 30%, is recommended to ensure durability. For low-traffic applications, higher RCA content (up to 40%) can be utilized without compromising performance.

5. Conclusion

This study demonstrates the feasibility of using RCA in road base construction in Mauritius. The 30% to 40% RCA blend offers a strong balance of mechanical performance, environmental sustainability, and cost-effectiveness. The reduction in CO2 emissions and energy consumption highlights RCA's potential as a key material in the transition to sustainable infrastructure development. However, further research is needed to assess the long-term durability of RCA mixes in real-world conditions and to explore the potential for optimizing RCA quality through improved recycling processes.

Future studies should also focus on life cycle assessments (LCAs) to quantify the environmental and economic benefits of RCA over the full life span of road infrastructure. Additionally, exploring advanced mix designs that incorporate other recycled materials, such as reclaimed asphalt pavement (RAP), could further enhance the sustainability of road base materials.

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