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Comparative Analysis of Recycled Concrete Aggregate and Waste Ceramic Tile as Coarse Aggregate Replacement in Concrete Based on Flexural Strength for Rigid Pavement Applications

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ABSTRACT: This study evaluates the flexural performance of concrete incorporating recycled concrete aggregate (RCA) and waste ceramic tile (WCT) as partial replacements for natural coarse aggregates for rigid pavement applications in accordance with Department of Public Works and Highways standards. Replacement levels of 10%, 20%, and 30% were investigated alongside a control mix. Physical properties, including soundness, abrasion resistance, wash loss, absorption, specific gravity, and unit weight, were determined using standard laboratory tests. Flexural strength was evaluated at 7 and 14 days using the modulus of rupture test under midpoint loading. Results showed that RCA satisfied all physical property requirements and maintained values comparable to natural aggregates, while WCT exhibited reduced density at higher replacement levels. RCA mixtures consistently exceeded the required flexural strengths of 2.53 MPa (7 days) and 4.5 MPa (14 days), whereas WCT failed to meet the 14-day requirement beyond the control mix. Statistical analysis indicated no significant differences for RCA ($p > 0.05$) and significant reductions for WCT ($p < 0.001$). These findings confirm that RCA can be effectively used as a sustainable coarse aggregate for rigid pavement applications up to 30% replacement, while WCT is only suitable at low replacement levels or for non-structural use.

KEYWORDS*:* Recycled Concrete Aggregate (RCA); Waste Ceramic Tile (WCT); Flexural Strength; Rigid Pavement; Sustainable Concrete

I. INTRODUCTION

The rapid expansion of infrastructure development in the Philippines has led to a significant increase in construction and demolition waste, creating environmental and resource management challenges. Road repair and rehabilitation, along with the widespread use of ceramic tiles in buildings, contribute heavily to this issue. While essential to development, these activities generate large amounts of waste that are often underutilized or improperly disposed of.

Road maintenance is a continuous necessity due to traffic demand, weather conditions, and material deterioration. However, removed concrete pavements are commonly discarded or stockpiled without reuse, despite their potential as recycled concrete aggregate (RCA). This practice leads to inefficient resource use and environmental degradation.

Similarly, ceramic tile usage continues to grow with urbanization. During installation, tile off-cuts and broken pieces are produced in large quantities and are typically treated as waste, even though they retain useful mechanical properties. As a result, these materials accumulate in construction sites and disposal areas, worsening solid waste problems.

These practices highlight a gap in sustainable construction, particularly in reusing construction by-products. Incorporating recycled materials into new construction aligns with global sustainability goals, such as the United Nations Sustainable Development Goals (SDGs), specifically SDG 9, SDG 11, and SDG 12, which promote resilient infrastructure, sustainable cities, and responsible resource use.

In rigid pavement engineering, concrete is primarily designed based on flexural strength due to bending stresses from traffic loads. However, many studies focus more on compressive strength, overlooking flexural performance. This presents an opportunity to evaluate alternative aggregates based on flexural behaviour.

This study investigates the use of recycled concrete aggregate from demolished pavements and waste ceramic tile fragments as partial replacements for natural coarse aggregates. By focusing on flexural strength, it aims to reflect actual pavement conditions while addressing construction waste issues. The research also explores how these materials can reduce reliance on natural resources and support sustainable construction.

Ultimately, the study seeks to bridge the gap between waste generation and material reuse in the Philippine construction industry, contributing to more sustainable and efficient infrastructure development.

A. General Objective

To evaluate and compare the flexural strength of concrete incorporating recycled concrete aggregates (RCA) and waste ceramic tile (WCT) fragments at 10%, 20%, and 30% replacement levels, using a control mix (0% replacement), in order to determine their suitability as sustainable coarse aggregate alternatives for rigid pavement applications in accordance with Department of Public Works and Highways (DPWH) standards.

B. Specific Objective

1. To determine the physical properties (such as soundness, abrasion resistance, wash loss, moisture content, specific gravity, absorption, and unit weight) and mechanical properties of natural coarse aggregates (control), recycled concrete aggregates (RCA), and waste ceramic tile (WCT) fragments using standard laboratory tests.
2. To prepare, produce, and cure concrete mixtures and beam specimens using a control mix (0% replacement) and partial replacement levels of 10%, 20%, and 30% for each material.
3. To determine the flexural strength of the concrete specimens at 7 and 14 days using the modulus of rupture test under midpoint loading.
4. To analyze and compare the flexural strength results using descriptive statistics (mean and standard deviation) and inferential analysis through one-way ANOVA, with post hoc analysis applied when significant differences are observed.
5. To evaluate compliance and identify the most suitable replacement level based on Department of Public Works and Highways (DPWH) standards and to propose sustainable alternatives for rigid pavement applications.

II. METHODOLOGY

Crushed concrete pavement was sourced from road repair activities and subsequently processed at a crusher plant to produce recycled concrete aggregates (RCA). Waste ceramic tiles (WCT) were obtained from construction debris and processed for use as partial coarse aggregate replacement. The physical properties of the aggregates were determined through laboratory testing, including soundness, abrasion loss, wash loss, moisture content, bulk specific gravity, water absorption, and unit weight. All tests were conducted in accordance with applicable ASTM standards to verify compliance and suitability for concrete production.

Concrete mixtures were prepared using a control mix (0% replacement) and partial replacement of coarse aggregates at 10%, 20%, and 30% for both recycled concrete aggregates (RCA) and waste ceramic tile (WCT) fragments. Beam specimens measuring 150 mm × 150 mm × 450 mm were cast, with three specimens produced per mix and curing period, resulting in a total of 42 specimens. After 24 hours, the specimens were demolded and cured in water. Flexural strength testing was conducted at 7 and 14 days using the modulus of rupture test under midpoint loading in accordance with ASTM C293. The maximum load at failure was recorded, and the flexural strength was computed using standard equations.

Descriptive statistics, including mean and standard deviation, were used to summarize the results. One-way Analysis of Variance (ANOVA) was performed to determine significant differences among replacement levels, with post hoc analysis applied when necessary. The results were evaluated based on Department of Public Works and Highways (DPWH) standards to identify the most suitable replacement level and assess the potential of RCA and WCT as sustainable materials for rigid pavement applications.

Figure I. Research Flow

III.RESULTS AND DISCUSSION

Physical Properties

The results of the physical and mechanical tests are presented and analysed to evaluate the performance of RCA and WCT as partial aggregate replacements.

Table I Physical Properties of Recycled Coarse Aggregates

Physical Property	Standard Limit	0%	10%	20%	30%	Status
Soundness (Na_2SO_4)	Max 12%	8.07	7.79	7.50	7.22	PASS
Abrasion Loss (L.A.)	Max 40% - 50%	17.17	17.76	18.34	18.93	PASS
Wash Loss (No. 200)	Max 1.0%	0.50	0.49	0.48	0.48	PASS

Absorption (%)	Max 2.0% - 3.0%*	0.50	0.55	0.58	0.62	PASS
Specific Gravity	2.40 – 2.90	2.63	2.62	2.62	2.61	PASS
Moisture Content	Field Specific	0.91	0.91	0.91	0.92	NORMAL
Unit Weight (Loose)	> 1120 kg/m³	1652	1608	1563	1519	PASS
Unit Weight (Rodded)	> 1120 kg/m³	1826	1787	1748	1709	PASS

The physical properties of the Recycled Concrete Aggregate (RCA) mixtures at 0%, 10%, 20%, and 30% replacement levels are presented in Table I. All mixtures satisfied the specified limits of ASTM and the Department of Public Works and Highways, indicating that the use of RCA did not compromise the overall quality of the aggregates.

In terms of durability, the soundness values ranged from 7.22% to 8.07%, which are well below the maximum allowable limit of 12%. A decreasing trend in soundness loss was observed with increasing RCA content, suggesting improved resistance to weathering. Abrasion loss values (17.17%–18.93%) also remained significantly lower than the allowable range of 40%–50%, indicating high resistance to wear. Wash loss values were consistently low (~0.48%–0.50%), confirming the cleanliness of the aggregates.

Absorption values showed a gradual increase from 0.50% to 0.62% with higher RCA content due to its more porous nature, while specific gravity slightly decreased from 2.63 to 2.61. Moisture content remained stable (0.91%–0.92%), and both loose and rodded unit weights decreased as RCA increased, reflecting its lower density. However, all values remained within acceptable limits, supporting the use of RCA as a sustainable alternative to natural aggregates without significant loss of performance.

Table II Physical Properties of Waste Ceramic Tiles

Physical Property	Standard Limit	0% (Ref)	10%	20%	30%	Status
Soundness (Na_2SO_4)	Max 12%	8.07	5.2	5.4	5.6	PASS
Abrasion Loss (L.A.)	Max 40% - 50%	17.17	22.0	23.0	24.0	PASS
Wash Loss (No. 200)	Max 1.0%	0.50	0.37	0.39	0.41	PASS
Absorption (%)	Max 2.0% - 3.0%*	0.50	0.55	0.52	0.48	PASS
Specific Gravity	2.40 – 2.90	2.63	2.48	2.24	2.01	LOW
Moisture Content	Field Specific	0.91	0.90	0.91	0.91	NORMAL
Unit Weight (Loose)	> 1120 kg/m³	1652	1179	1026	874	FAIL*
Unit Weight (Rodded)	> 1120 kg/m³	1826	1410	1240	1070	FAIL*
Soundness (Na_2SO_4)	Max 12%	8.07	10%	20%	30%	Status

As shown in Table II, WCT mixtures met durability and cleanliness requirements, with soundness (5.2–5.6%) and abrasion loss (22–24%) within allowable limits. However, significant reductions in specific gravity (2.63 to 2.01) and unit weight were observed. At 20% and 30% replacement, unit weight fell below standard requirements, indicating a transition to lightweight aggregate behavior and a less compact internal structure that may affect mechanical performance.

These changes are attributed to the more porous and less dense nature of waste ceramic tile, which increases void spaces and reduces interparticle packing as replacement levels rise. While higher WCT content may reduce strength, lower replacement levels still show acceptable properties, making them suitable for non-structural or lightweight applications. This suggests that WCT can be strategically utilized where reduced weight is advantageous without critically compromising performance. Proper mix design adjustments may further enhance its applicability in construction.

Mechanical Properties- Flexural Strength

The results of the mechanical tests, particularly the flexural strength test, are presented and analyzed to evaluate the performance of RCA and WCT as partial replacements for natural coarse aggregates. This section focuses on the behavior of the concrete mixtures under bending, providing insight into their load-carrying capacity and suitability for rigid pavement applications.

Table III Flexural Strength Test Result of Recycled Concrete Aggregates (RCA)

% RCA	7 Days (MPa)	14 Days (MPa)
0%	3.12	5.54
10%	3.14	5.50
20%	3.21	5.15
30%	3.23	4.56

Table IV Flexural Strength Test Result of Waste Ceramic Tiles (WCT)

% WCT	7 Days Flexural Strength (MPa)	14 Days Flexural Strength (MPa)
0%	3.12	5.54
10%	3.10	4.17
20%	2.98	4.05
30%	2.83	3.98

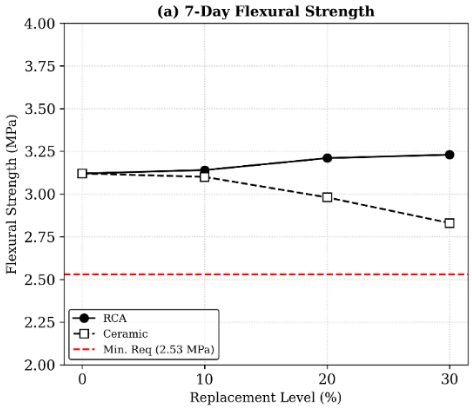

Figure II. Comparison of Flexural Strength Test Result Between RCA and WCT at 7 days

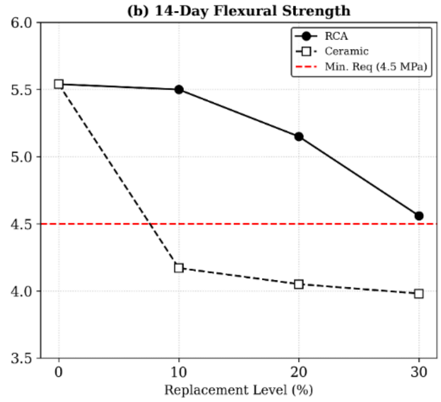

Figure II. Comparison of Flexural Strength Test Result Between RCA and WCT at 14 days

The flexural strength results are presented in Table Z and evaluated based on Department of Public Works and Highways requirements of 2.53 MPa at 7 days and 4.5 MPa at 14 days.

RCA mixtures exceeded the required strength at both curing periods, with values ranging from 3.12–3.23 MPa (7 days) and 5.54–4.56 MPa (14 days). Despite a slight decrease at higher replacement levels, all results remained above the required limits, indicating stable structural performance.

In contrast, WCT mixtures met the 7-day requirement but failed to meet the 14-day requirement beyond the control mix. Flexural strength decreased from 5.54 MPa to 3.98 MPa with increasing replacement, indicating reduced load-carrying capacity. This decline is attributed to the lower density and brittle nature of ceramic aggregates, which weaken bonding and stress transfer under bending.

Summary of One-Way ANOVA for Flexural Strength

Table V One Way ANOVA

Aggregate Type	Age (Days)	p-value	Significance Level (α = 0.05)	Decision	Interpretation
RCA	7 Days	> 0.05	0.05	Not Significant	No effect of replacement level
	14 Days	> 0.05	0.05	Not Significant	Strength remains statistically similar
WCT	7 Days	< 0.001	0.05	Significant	Replacement affects strength
	14 Days	< 0.001	0.05	Significant	Strong reduction in flexural strength

As shown in Table AA, RCA mixtures exhibited no significant difference across replacement levels at both curing periods ($p > 0.05$), indicating that RCA does not significantly affect flexural strength.

In contrast, WCT mixtures showed highly significant differences ($p < 0.001$), confirming that increasing ceramic content significantly reduces flexural strength. This statistical result supports the observed decreasing trend and highlights the sensitivity of flexural performance to WCT replacement levels.

CONCLUSIONS

This study evaluated the physical and mechanical performance of recycled concrete aggregate (RCA) and waste ceramic tile aggregate (WCT) as partial replacements for natural coarse aggregates in rigid pavement concrete, in accordance with the Department of Public Works and Highways standards. In addition to strength and physical properties, the workability of the mixtures was also assessed through slump tests to determine the effect of aggregate replacement on fresh concrete behavior.

The results indicate that RCA satisfies all required physical property limits, including durability, cleanliness, and density, and remains comparable to conventional aggregates across all replacement levels. In terms of workability, RCA mixtures showed a slight reduction in slump as the replacement level increased, which can be attributed to the higher absorption and rougher surface texture of RCA.

However, the slump values remained within acceptable ranges for pavement concrete, indicating that proper mix design can maintain adequate workability. In terms of mechanical performance, RCA mixtures consistently exceeded the required flexural strengths of 2.53 MPa at 7 days and 4.5 MPa at 14 days under midpoint loading. Statistical analysis further confirmed that variations in flexural strength were not significant ($p > 0.05$), indicating that RCA can be used up to 30% replacement without adversely affecting structural performance.

In contrast, WCT exhibited acceptable durability and cleanliness but showed significant reductions in specific gravity and unit weight at higher replacement levels, indicating a transition toward lightweight aggregate behavior. The slump of WCT mixtures also decreased more noticeably with increasing replacement, suggesting reduced workability due to the angular shape and lower density of the material. While WCT mixtures met the 7-day strength requirement, they failed to meet the 14-day requirement beyond the control mix. The decrease in flexural strength with increasing replacement was statistically significant ($p < 0.001$), confirming that WCT negatively affects flexural performance at higher replacement levels.

Overall, the findings demonstrate that RCA is a suitable and reliable sustainable alternative for coarse aggregate in rigid pavement applications, while WCT is limited in structural use and is more appropriate at low replacement levels or for lightweight and non-structural concrete applications. The inclusion of slump test results further supports that, although both materials influence workability, RCA maintains a better balance between fresh and hardened concrete properties compared to WCT.

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