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Predictive Analysis of Flexural Strength of Concrete Using Recycled Concrete Aggregates: A Preliminary Statistical Approach

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ABSTRACT: The increasing scarcity of natural coarse aggregates (NA) in areas such as Nueva Ecija highlights the urgent need to explore sustainable alternatives in concrete production. Recycled concrete aggregates (RCA), derived from construction and demolition waste, offer a promising substitute that supports resource efficiency and environmental sustainability. This study aims to evaluate the feasibility of using RCA as a replacement for NA by predicting its effect on the flexural strength of concrete. A simple linear regression model was developed based on experimental data comparing concrete specimens made with 0% and 100% RCA. The model estimates flexural strength at 14 days for varying RCA content levels. Results indicate a consistent decline in strength as RCA content increases; however, concrete mixes with up to approximately 80% RCA are predicted to meet the Department of Public Works and Highways (DPWH) minimum flexural strength requirement of 3.45 MPa. Despite limitations in sample size, the findings provide early evidence that significant RCA replacement is structurally viable. This study contributes to the pursuit of sustainable infrastructure by aligning with the United Nations Sustainable Development Goals (SDG 9, 11, and 12), advocating for innovation, urban resilience, and responsible material use.

KEYWORDS: Recycled Concrete Aggregate, Flexural Strength, Linear Regression, Sustainable Construction, Coarse Aggregate Replacement

I. INTRODUCTION

Concrete remains the most extensively used construction material worldwide due to its versatility, availability, and structural performance. However, the increasing emphasis on sustainability and the environmental impacts of construction activities has prompted a shift toward more responsible material consumption. One emerging solution is the use of recycled concrete aggregate (RCA) as a partial or full replacement for natural aggregate (NA). RCA is produced from crushed concrete pavements and other demolished concrete structures, providing a means to reduce dependence on natural resources while simultaneously diverting construction and demolition waste from landfills.

Despite its environmental benefits, the incorporation of RCA into concrete mixes can significantly influence the material's physical and mechanical characteristics. Numerous studies have reported that higher RCA content may result in reduced workability, lower density, and diminished strength properties due to the porous nature of the adhered mortar and weaker interfacial bonding within the recycled particles. Among these mechanical properties, flexural strength is of particular importance, especially in infrastructure applications such as pavements, where resistance to bending stresses is critical.

This study aims to explore the predictive relationship between RCA content and the flexural strength of concrete. Using a statistical modelling approach, specifically linear regression, the research seeks to estimate flexural strength based on limited experimental data. The objective is to offer an efficient, low-resource method for assessing the structural viability of RCA-based concrete without the immediate need for extensive laboratory testing.

A. General Objective

To investigate the potential of recycled concrete aggregates (RCA) in concrete production by predicting their effect on flexural strength using statistical modelling and evaluating workability through slump tests.

B. Specific Objective

1. To measure and compare the slump values of concrete mixtures containing 0% and 100% recycled concrete aggregate (RCA).
2. To determine the flexural strength of concrete specimens incorporating natural and recycled aggregates after 14 days of curing.
3. To develop a simple linear regression model to establish the relationship between RCA content and flexural strength.
4. To estimate the flexural strength of concrete at intermediate RCA replacement levels (25%, 50%, and 75%) using the developed regression model.
5. To identify the maximum RCA replacement level at which the predicted flexural strength satisfies

the Department of Public Works and Highways (DPWH) minimum standard of 3.45 MPa.

II. METHODOLOGY

Crushed concrete pavement was sourced from road repairs along Vergara Highway in Cabanatuan City and processed at the CCF crusher plant in Valle Cruz to produce recycled concrete aggregates (RCA), which were used as coarse aggregates in the alternative mix. For the control mix, commercially purchased natural coarse aggregates were used. Fine aggregates and Portland cement were also acquired. Molds (150mm x 150mm x 510mm) were fabricated using phenolic plyboard. A 1:2:3 mix ratio (cement:fine:coarse aggregates) was followed. Two sets of concrete were prepared—one with natural aggregates (control) and one with RCA as coarse aggregates (alternative).

After preparation, a slump test was conducted on each mix to evaluate the workability, providing insight into the effects of RCA on the fresh properties of the concrete. The concrete samples were then cured for 14 days, after which flexural strength testing was performed in accordance with ASTM C78 (Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Third-Point Loading) to assess structural performance.

A predictive analysis was carried out using data from six samples—three containing 0% RCA and three with 100% RCA. The type of aggregate used was encoded as a binary independent variable, with 0 for natural aggregate and 1 for RCA. Using the collected flexural strength data, a simple linear regression model was developed to analyze the relationship between RCA content and flexural strength. This model was then used to predict the flexural strength of concrete at intermediate RCA replacement levels of 25%, 50%, and 75%. Finally, the predicted values were evaluated against the minimum flexural strength requirement of 3.45 MPa, as specified by the Department of Public Works and Highways (DPWH), to assess structural adequacy.

Figure II. Natural Aggregates (Left) Recycled Concrete Aggregate (Right)

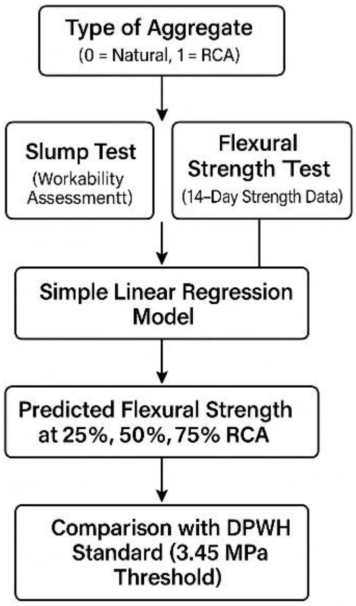

Figure II. Research Flow

Figure III. Flexural Strength Test

III.RESULTS AND DISCUSSION

The slump test shows that increasing RCA content reduces workability due to its higher water absorption. Despite this, the reduction in workability does not notably affect flexural strength, indicating that RCA can still be effectively used in concrete. Proper mix adjustments, such as modifying the water-cement ratio or adding admixtures, can minimize the impact on workability while maintaining adequate strength.

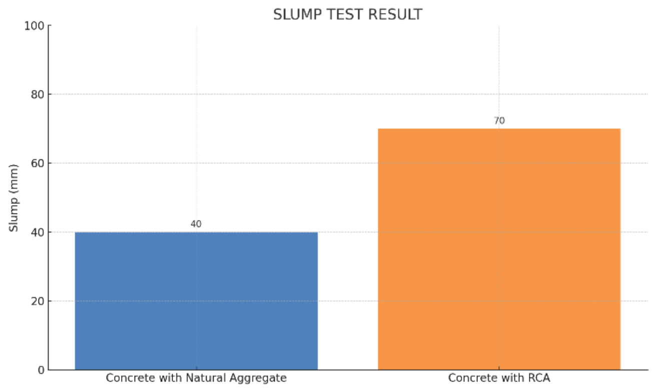

Figure III. Slump Test

A simple linear regression model was developed to examine the effect of Recycled Concrete Aggregate (RCA) content on the flexural strength of concrete. The model equation is:

Flexural Strength (MPa) = 4.10 − 0.72 × (RCA Fraction)

Where:

RCA Fraction = percentage of RCA used, expressed as a decimal (e.g., 25% = 0.25)

Using this model, the predicted flexural strengths at various RCA replacement levels are shown below:

Table I Predicted Flexural Strength

RCA Content (%)	Predicted Flexural Strength (MPa)
0	4.10
25	3.92
50	3.74
75	3.56
100	3.38

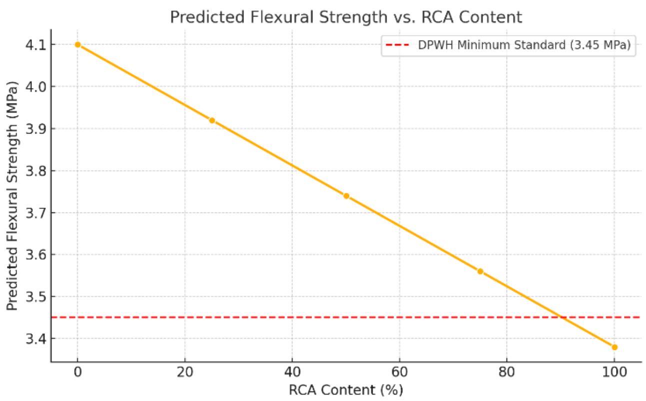

Figure III. Predicted Flexural Strength vs. RCA Content

The results demonstrate a consistent linear decrease in flexural strength as the RCA content increases. This negative correlation can be attributed to the physical characteristics of RCA, particularly the presence of adhered mortar, which leads to higher porosity and water absorption. These microstructural weaknesses reduce the integrity of the cement-aggregate bond, thereby lowering the overall mechanical performance of the concrete.

The DPWH minimum flexural strength requirement is 3.45 MPa. Based on the regression model, the flexural strength of concrete is predicted to fall below this threshold when RCA content exceeds approximately 80%. This indicates that RCA can be used as a partial replacement for natural aggregates—up to 75%—while still meeting structural code requirements. These findings are consistent with existing literature, which commonly reports a decline in strength properties as RCA content increases, due to the inherently lower quality of the recycled material.

CONCLUSIONS

This study demonstrates the potential of Recycled Concrete Aggregates (RCA) as a viable and sustainable alternative to natural aggregates in concrete production. The analysis revealed a linear decrease in flexural strength as the RCA content increased, primarily due to the inherent properties of RCA, such as higher porosity and the presence of residual mortar. However, the regression model indicates that RCA can be incorporated at replacement levels of up to 75–80% without causing the flexural strength to fall below the minimum requirement of 3.45 MPa set by the Department of Public Works and Highways (DPWH). This suggests that RCA can be safely used in structural applications with partial replacement, aligning with both engineering standards and environmental goals.

The slump test results further indicate a reduction in workability with increasing RCA content, which is likely due to the greater water absorption capacity of the recycled material. Nevertheless, this reduction in workability does not proportionally translate into a significant loss in flexural strength, highlighting RCA's potential as a practical material for concrete production under proper mix adjustments.

These findings underscore the feasibility of using RCA as a resource-efficient and eco-friendly material, particularly in areas like Nueva Ecija, where the supply of high-quality natural aggregates is becoming increasingly constrained. Incorporating RCA not only supports sustainable construction practices but also contributes to waste reduction by diverting demolished concrete from landfills.

For broader applicability and more robust conclusions, future research is recommended. Expanding the dataset to include more samples and a wider range of RCA contents, as well as considering additional mix design variables such as water-cement ratio, curing conditions, and aggregate grading, will help enhance the predictive power of the regression model. Long-term durability studies and performance assessments under various environmental conditions would also be valuable in verifying the structural integrity and service life of RCA-based concrete in real-world applications.

In summary, RCA holds significant promise for promoting sustainable development in civil engineering, offering a balance between performance, environmental responsibility, and material efficiency.

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