Compressive Performance of Normal Strength Concrete with Varying Percentages of Recycled Portland Cement Concrete Pavement as Coarse Aggregate

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Abstract: - This study was conducted to assess the compressive performance of normal strength (20 N/mm2 to 40 N/mm2) concrete with varying percentages (0%, 25%, 50%, 75 %, and 100%) of recycled Portland Cement Concrete Pavement (PCCP) as coarse aggregates. Due to a lack of understanding and researches, it is not widely utilized in infrastructure construction, but it is used in the construction of highways and embankments. The effects of varying percentage of RCA on the compressive strength (CS), physical characteristics, and durability of such concretes have been established. The results revealed that up to 100% RCA had no effect on the concrete's compressive performance. There is an evident rise in CS as the RCA replacement percentage increases up to 75%, then a gradual drop as the RCA replacement percentage increases further. Despite this, all of the concretes containing RCA outperformed the CS of non-RCA concrete, wherein the 75% RCA replacement percentage yields the highest compressive strength with 27.11 MPa that is 28% higher than the CS of non -RCA concrete. The study confirms that normal-strength RCA concrete will have the same engineering performance in terms of compressive strength similar with concrete prepared with natural aggregates and is promising for maximizing knowledge and advancing sustainable construction in the country. With continuous construction, and rehabilitation projects, there will be more prospects for the use of RCA.

Key Words: - ***PCCP, Recycled coarse aggregate, ASTM, Aggregate Test, Compressive Strength.***

I. INTRODUCTION

Sustainability is a top priority when we are using wide variety of natural resources to produce materials such as concrete. The depletion of natural resources and the increasing demand for aggregates must be addressed in an efficient manner (Biol et al. 2015).

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And with the rapid urbanization and construction development, the demand for natural aggregate is increasing day by day, along with the increase of concrete production.

Construction and demolition (C&D) waste management is a significant concern. Concrete waste from C&D operations is dumped in landfills, which harms the environment (Saddi & Cosares, 2019). As an alternative, concrete scrap could be recycled, utilized, and processed to make concrete by replacing natural coarse aggregates (NCA) by a recycled one.

It is acknowledged that one practical method for successfully utilizing recycled coarse aggregates (RCA) is to replace the NCA in concrete with building and demolition debris (Abdulla, 2015). In general, RCA are made from collected C&D wastes from construction, renovation, and demolition operations such as civil works, site clearance, road construction, land excavation or grading, and demolition activities (Environmental Protection Agency, 1998). Generating RCA from these wastes would save resources by reducing the number of raw materials needed especially in the construction industry.

One of the primary issues in the use and application of RCA in concrete application is its high variability in performance which lead to its limited use in construction industry. Due to a lack of understanding and researches, it is not yet utilized in wide varieties of infrastructure projects, but it is used in the construction of highways and embankments (Abhishek et al, 2022). The reason can be traced out from the variation of C&D waste sources and inappropriate landfill disposal, wherein C&D wastes are often not sorted out which causes the inconsistencies in its performance. It is important to take note that RCA made from demolished bricks, woods, and other C&D waste is different from RCA generated from concrete debris, especially those from demolished PCCP. For this reason, the RCA in this study was generated entirely from demolished Portland Cement Concrete Pavement (PCCP). In this way, variabilities are minimized and the results will be more substantial and specific for the use of PCCP as source of recycled coarse aggregate. Furthermore, due to pavement design, crushing and generation of coarse aggregate from PCCP is a lot easier due to less steel reinforcement embedded in it.

Hence, this study was conducted to assess the compressive performance of normal strength concrete with varying percentages of recycled Portland Cement Concrete Pavement as coarse aggregate, summarizing the most significant research findings from the past years discussing the material features of RCA and its suitability in normal strength concrete applications.

II. OBJECTIVES

2.1 General Objective

The general objective of this study is to assess compressive performance of normal strength concrete with varying percentages of recycled portland cement concrete pavement as coarse aggregate.

2.2 Specific Objectives

a. Assess the suitability of RCA generated from PCCP as coarse aggregate using the following coarse aggregate tests:
   - Absorption Test
   - Clay Lump Test
   - Coarse Aggregate Specific Gravity Test
   - Gradation Test
   - Los Angeles Abrasion Test
   - Unit Weight Test

b. If the RCA is suitable for use, a mix of recycled coarse aggregates and natural coarse aggregates of different percentages computed by weight will then be prepared.
   - 0 percent recycled coarse aggregates, 100 percent natural coarse aggregate
   - 25 percent recycled coarse aggregates, 75 percent natural coarse aggregate
   - 50 percent recycled coarse aggregates, 50 percent natural coarse aggregate
   - 75 percent recycled coarse aggregates, 25 percent natural coarse aggregate
   - 100 percent recycled coarse aggregates, 0 percent natural coarse aggregate

c. Assess the effect of RCA to the resulting coarse aggregate properties, under the following test:
   - Absorption Test
   - Specific Gravity Test
   - Rodded and Loose Unit Weight Test

d. Prepare a fresh concrete mix.

e. Conduct a slump test to determine the effect of RCA on the degree of workability of each concrete mix.

f. Perform the curing process for 7 and 14 days or until target strength is acquired.

g. Perform compressive test on the hardened concrete.

III. METHODOLOGY

3.1 Research Design

An experimental study conducted to statistically assess normal strength concrete mixtures with varying replacement of RCA (0%, 25%, 50%, 75 %, and 100%) to NCA in order to determine the correlation of RCA replacement percentage and compressive strength and RCA properties. The purpose of the experimental investigation is to assess the competency and applicability of varying replacement percentages of RCA in normal strength concrete mix. Compressive strength is used to evaluate the material's suitability for construction and the generated samples are then examined after 7 and 14 days of curing or until the desired strength is achieved.

3.2 Research Setting

The study is carried out at the Nueva Ecija University of Science and Technology (NEUST), which is situated in Sumacab, Cabanatuan City, Nueva Ecija, Philippines. All RCA are taken from a pavement in Macabucod, Aliaga, Nueva Ecija, Philippines, crushed into aggregate at Celso C. Ferrer Contractor, which is located at Barangay Mampulog, Bitas, Cabanatuan City, Nueva Ecija, Philippines and further tested at Nueva Ecija Materials Testing Center located at Barangay Bantug Norte, Cabanatuan City, Philippines. Samples are then batch and cured for 7 and 14 days at Purok 1, Sta. Rita, Jaen, Nueva Ecija, Philippines as well as the samples' Slump Test. Compressive tests are conducted at Nueva Ecija Materials Testing Center.

3.3 Materials

Coarse aggregates used is a combination of natural and recycled coarse aggregates. The NCA and fine aggregates are a readily market-available aggregate from Macabucod, Aliaga, Nueva Ecija, Philippines, while the RCA are crushed reclaimed concrete chunks from Macabucod, Aliaga, Nueva Ecija, Philippines having size ranging from 19.05 mm or 0.75 inches to 25.4 mm or 1 inches since it is the available size for the crusher. In order to facilitate the concrete batching procedures for the test mixes, NCA and RCA are combined in a desired percentage to produce the coarse aggregate mix. Fine aggregates and cement (Eagle Cement Advance) are locally market - available ones. The water that is used is drinkable, no further test is conducted.

3.4 Concrete Mix Design

The study included the design of five different concrete mixes in or 1:1.5:3 cement, fine aggregate, and coarse aggregate ratio computed by weight which is equivalent to the Fajardo Class AA concrete and is similar to the M20 design mix of concrete used by Abhishek et. al (2022) and Tiwari et. al (2021). Cement-water ratio was kept uniform at 0.5 for all the concrete mixes. The RCA content of coarse aggregate are varied as 0%, 25%, 50%, 75% and 100%. The concrete mix design utilized are summarized in table 3.

3.5 Sample Preparation

The specimen is a 150 mm cube sample with the specified amounts of cement, aggregate, and water and were designated with the following codes: RCA-0 (0% recycled Coarse aggregate and 100% natural coarse aggregates), RCA-25 (0% recycled Coarse aggregate and 100% natural coarse aggregates), RCA-50 (25% recycled Coarse aggregate and 75% natural coarse aggregates), RCA-75 (50% recycled Coarse aggregate and 50% natural coarse aggregates), and RCA-100 (100% recycled Coarse aggregate and 0% natural coarse aggregates) computed by weight with each having 3 replications and are cured for 7 and 14 days.

3.6 Data Gathering Procedures

The experimental program is divided into two phases: Phase 1 focuses on evaluating RCA qualities, and Phase 2 focuses on assessing the compressive strength of concretes and different percentage of RCA replacement.

Properties of the recycled aggregates are determined using several coarse aggregate tests. The Gradation test, Specific Gravity Test, Loss Angeles Abrasion Test, Absorption Tests, Clay Lump Test, and Unit Weight Test, are calculated using the techniques described in ASTM.

The mixing procedure begun after all materials were gathered. All aggregates are mixed and a slump test is performed. Several things are considered, if the slump constraint is achieved, the mixing process continue. If not, additional water will be added and the mixture will be mix again prior to a second slump test. Cube molds are rodded and the samples generated are submerged into fresh water. All samples are then allowed to cure for 7 and 14 days or until the sample reached the target strength.

Lastly, tests for compressive strength is performed. It evaluates the concrete cubes' resistance to failure due to compression.

3.7 Instruments

In this study, a slump cone with a 100 mm top, 200 mm base and 300 mm height were used to test for workability in accordance with ASTM C-143: Standard Test Method for Slump of Hydraulic-Cement Concrete. A 5/8-inch metal rod was also used in the procedure in accordance with the ASTM C-31 and ASTM 143 and a compression machine.

Observation is the primary method of data collection as several experiments are conducted according to various test criteria. The reason the researchers opt for observation is that method is appropriate for gathering quantitative data and allows for the tabulation and recording of outcomes following an experiment. Each test has its own criteria and guidelines, which must be strictly followed in order to achieve the observable features that determined the specimen's results. The effectiveness of the study is based on the batch formulation of various concrete samples with varying percentages of recycled and coarse aggregate.

3.8 Statistical Treatment

Pearson's correlation coefficient (r) is used as a measure of the relationship between RCA replacement and compressive strength. It is typically represented with a graphical representation of the relationship between data pairs, such as a scatter diagram. The correlation coefficient ranges from -1 to +1. Positive correlation coefficient values suggest a propensity for one variable to rise or decrease in tandem with another one. Negative correlation coefficient values suggest a propensity for an increase in one variable to be connected with a decrease in the other variable and vice versa. Correlation coefficient values close to zero suggest a weak relationship between two variables, whereas those close to -1 or +1 indicate a strong relationship between two variables.

With the help of this instrument, it became possible to anticipate the percentages required to produce results that are adequate and pass by the stated standards of various test processes and to be aware of the outcomes that might lead to samples that are insufficient.

IV. RESULTS

Table.1. Properties of recycled coarse aggregate

Type of Test	Results
Abrasion Test	25.18%
Absorption Test	2.09 %
Clay Lumps Test	0.177 %
Specific Gravity	2.5
Loose Unit Weight Test	1136 kg/m³
Rodded Unit Weight Test	1350 kg/m³

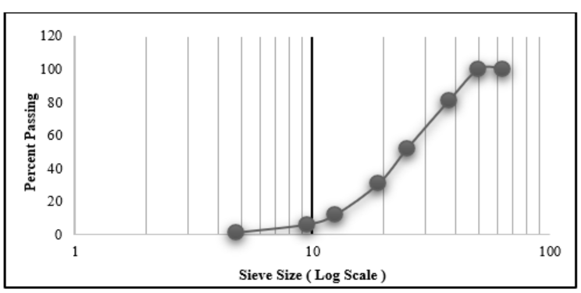

Fig.1. "As is" Particle Size Distribution of RCA after crushing

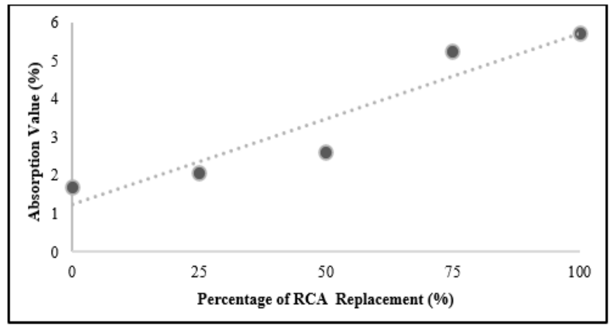

Fig.2. Relation of Absorption and Replacement of RCA

Table.2. Pearson Correlation Coefficients Between Absorption and RCA Replacement in Total Sample (N = 5)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Absorption of Resulting Coarse Aggregate	.945**	1

*Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

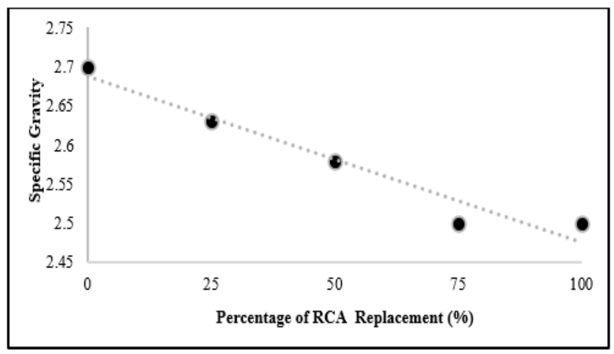

Fig.3. Relation of Specific Gravity and Replacement of RCA

Table.3. Pearson Correlation Coefficients Between Specific Gravity and RCA Replacement in Total Sample (N = 5)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Absorption of Resulting Coarse Aggregate	.974***	1

*Note: Two-tailed correlation denoted by *: p < .05, **: p < .01, ***: p < .001*

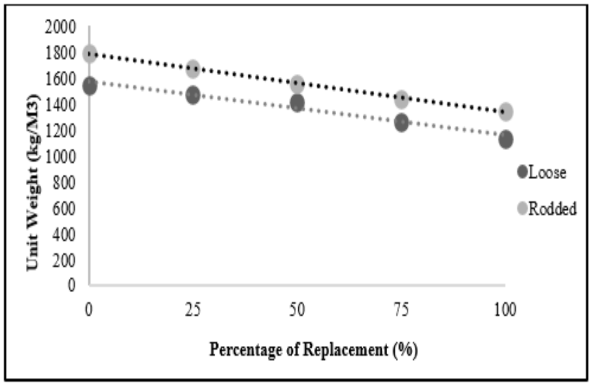

Fig.4. Relation of Unit Weight and Replacement of RCA

Table.4. Pearson Correlation Coefficients Between Loose Unit Weight and RCA Replacement in Total Sample (N = 5)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Absorption of Resulting Coarse Aggregate	.979***	1

*Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

Table.5. Pearson Correlation Coefficients Between Rodded Unit Weight and RCA Replacement in Total Sample (N = 5)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Absorption of Resulting Coarse Aggregate	.997***	1

*Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

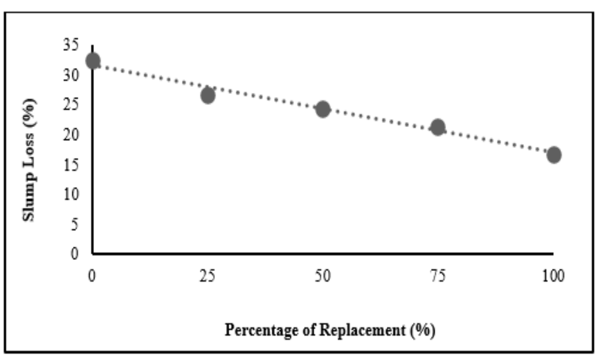

Fig.5. Relation of Slump Loss and Replacement of RCA

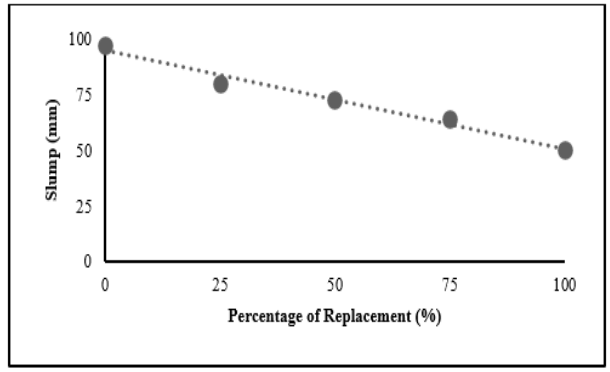

Fig.6. Relation of Slump Height and Replacement of RCA

Table.6. Pearson Correlation Coefficients Between Slump Loss Percentage and RCA Replacement in Total Sample (N = 5)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Absorption of Resulting Coarse Aggregate	.990***	1

*Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

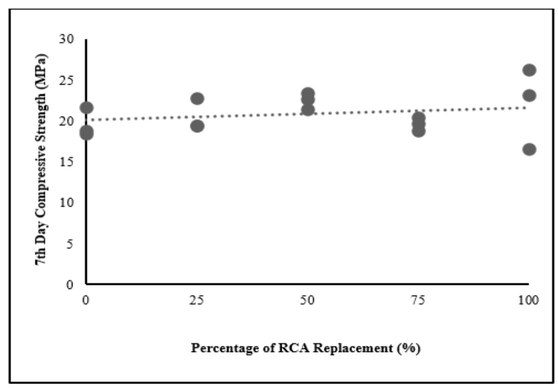

Fig.7. Relation of 7th Day Compressive Strength and Replacement of RCA

Table.7. Pearson Correlation Coefficients Between 7th Day Compressive Strength and RCA Replacement in Total Sample (N = 15)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Compressive Strength	.223	1

*Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

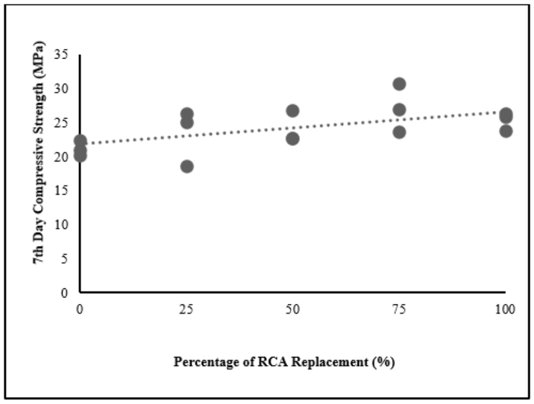

Fig.8. Relation of 14th Day Compressive Strength and Replacement of RCA

Table.8. Pearson Correlation Coefficients Between 14th Day Compressive Strength and RCA Replacement in Total Sample (N = 15)

Parameter	1	2
(1) Percentage of RCA replacement	1	
(2) Compressive Strength	.569**	1

`Note: Two-tailed correlation denoted by *: P < .05, **: P < .01, ***: P < .001*

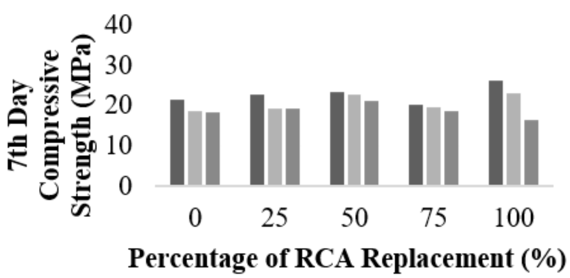

Fig.9. Compressive Strength of Cubes after 7 Days

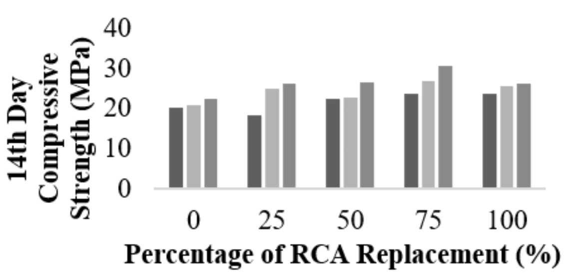

Fig.10. Compressive Strength of Cubes after 14 Days

V. CONCLUSION

The study was conducted to assess the compressive performance of normal strength concrete with varying percentages of recycled portland cement concrete pavement as coarse aggregate. The following conclusions can be drawn from the study's findings and analysis:

- The RCA generated was within the range of required abrasion loss and small amount of clay lumps is present. Therefore, RCA is suitable for use in normal concrete mix.
- Increase in replacement percentage of RCA cause a decrease in specific gravity and unit weight, but an increase in water absorption.
- The high demand for water of the RCA significantly affected the workability of mixtures. Meaning, higher RCA content causes lower workability of fresh concrete.
- RCA might replace NCA for up to 100% without suffering appreciable compressive strength loss in comparison to that of NCA concrete.
- 75% RCA replacement percentage yields the highest compressive strength. However, as RCA replacement percentage increase further it led to a decrease in compressive strength but still greater than NCA concrete.
- RCA concretes exhibit good compressive strength that is comparable to NCA concrete. It is possible to produce recycled concrete capable of outperforming the compressive strength of NCA concrete.
- With uniform design mix and cement-water ratio, higher RCA replacement result in higher compressive strength.

Hence, study's findings will help the issue in construction industry that had been noticed. The study is essential for reducing concrete waste by using RCA as a replacement for natural coarse aggregates in normal strength concrete mixes. Furthermore, this study also confirms that RCA from PCCP in the Philippines is not limited only for embankment purposes.

The study is promising for maximizing knowledge and advancing future sustainable construction in the Philippines. There will be more opportunities for the usage of RCA with building construction and rehabilitation projects here in the country.

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