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Treated Recycled Concrete Aggregate for Concrete Structural Members

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ABSTRACT

This study explored the innovative use of Recycled Concrete Aggregate (RCA) combined with Super Absorbent Polymers (SAP) as a sustainable alternative to Natural Aggregate (NA) in concrete production. Addressing the traditional limitation of RCA usage to 30% due to water absorption and reduced strength, this research successfully increased the RCA content to 50% using a Two-Stage Mixing Approach (TSMA). Three concrete mixtures were tested: conventional concrete and two mixtures containing 50% RCA and 50% NA, incorporating 0.11% and 0.3% SAP by cement weight. Compressive and flexural strength tests conducted on cylindrical and beam samples after 28 days revealed that the flexural strength of the recycled concrete mixtures was comparable to that of traditional concrete, meeting the standards set by the Department of Public Works and Highways (DPWH). Notably, the mixture with 50% RCA, 50% NA, and 0.3% SAP achieved the highest compressive strength, surpassing the American Concrete Institute (ACI) standard of 17 MPa (2500 PSI). These findings highlighted the potential of TSMA and SAP to enhance the structural performance of RCA-based concrete, making it a viable and sustainable alternative to conventional concrete. This study introduced a novel method for increasing RCA utilization in structural applications, significantly reducing construction waste and promoting environmentally sustainable practices in the construction industry.

Keywords: *Recycled Concrete Aggregate, Super Absorbent Polymers, Two-Stage Mixing Approach*

INTRODUCTION

The construction industry significantly impacts both economic development and environmental sustainability. As the demand for infrastructure continues to rise, the reliance on natural resources and the generation of construction waste have become pressing global challenges. One promising solution is using Recycled Concrete Aggregate (RCA), derived from construction and demolition waste, as a substitute for Natural Aggregate (NA) in concrete production. RCA addresses the waste disposal issue and reduces the strain on natural resources. However, its widespread adoption has been limited due to concerns about higher water absorption, reduced durability, and compromised structural performance. Current practices often restrict RCA usage to 30% in concrete mixtures, leaving a significant research gap in optimizing its use for broader applications.

This study addresses these limitations by investigating the feasibility of increasing RCA content to 50% in concrete. To overcome the durability and performance challenges associated with RCA, the research incorporates Super Absorbent Polymers (SAP), known for their ability to manage water absorption. It employs a Two-Stage Mixing Approach (TSMA) to enhance the material's properties. The study aims to evaluate the structural performance, including compressive and flexural strength, of concrete mixtures containing 50% RCA combined with SAP at varying proportions.

By focusing on the innovative integration of RCA, SAP, and TSMA, this research contributes to developing sustainable construction materials. It addresses critical environmental challenges while maintaining the structural integrity required for practical applications. The findings are expected to provide valuable insights into advancing the use of recycled materials in the construction industry, promoting sustainability without compromising performance.

Objectives of the Study

The study answered whether Recycled Aggregate Concrete mixed with Super Absorbent Polymers is a sustainable replacement for Natural Aggregates for creating reliable new concrete structural members. Specifically, the study determined the flexural and compressive strength of concrete mixtures with 50% Recycled Concrete Aggregate and 50% Natural Aggregate, incorporating either 0.11% or 0.30% Super Absorbent Polymers, and compared these to the flexural and compressive strength of conventional concrete. Finally, the study also assessed the significant differences in flexural and compressive strength between conventional concrete and the proposed mixtures, as well as between the two proposed mixtures.

Conceptual Framework

The research paradigm shown in Figure 1 depicted the research process on the two proposed mixed proportions of recycled concrete aggregate (RCA) with different percentages of super absorbent polymer (SAP) and traditional concrete, which formed the three concrete samples. The samples were subjected to compressive and flexural strength tests to identify the proportions that met the standard ASTM requirements for concrete structures.

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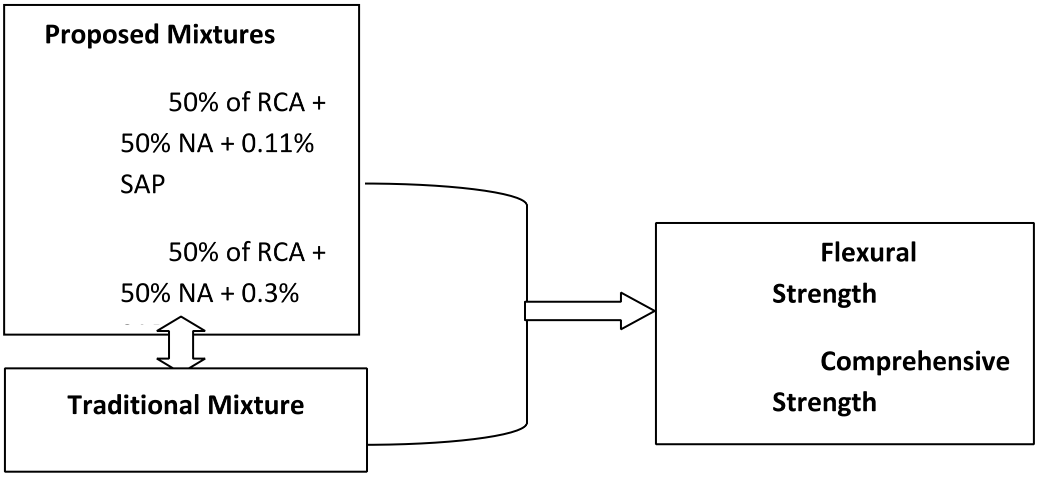

Figure 1
The Research Paradigm

Figure 1 shows the variance in the testing samples. The materials used were Natural Aggregate (NA), Recycled Concrete Aggregate (RCA), and Super Absorbent Polymer (SAP), which acted as a water-reducing admixture in treating concrete structural members. The proposed concrete mixtures for this research were as follows: Traditional Concrete for Variance A, 50% RCA + 50% NA + 0.11% SAP of the total cement mixture for Variance B, and 50% RCA + 50% NA + 0.3% SAP of the total cement mixture for Variance C. These mixtures were tested for compressive and flexural strength.

METHODOLOGY

This section discusses the research design, sampling, data gathering instrument, the gathering techniques and procedures, and the statistical treatment of the data.

Research Design

This research employed a quantitative experimental study. It focused on the quantity of Recycled Concrete Aggregates mixed with Natural aggregates to be used in concrete structural members with the addition of Super Absorbent Polymers as an admixture to attain the desired compressive and flexural strength. The samples were subjected to Compressive and Flexural Testing.

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Research Instrument

The Universal Testing Machine (UTM) was used for material testing and was designed to determine materials' compressive, tensile, shear, and flexural strength. A two-way load was applied perpendicular to the sample's surface until a crack formed. The UTM automatically recorded the maximum load displayed on the connected computer. The specimens were tested at the Material Testing Laboratory located at the Department of Public Works and Highways (DPWH) in Bantay, Ilocos Sur, using a calibrated Universal Testing Machine.

The experiment utilized a concrete mixture proportion of Class A or M15 (1:2:4). The conventional concrete followed the same concrete mixture. The percentage of RCA varied according to the volume of cement used in the concrete mixtures. The first sample consisted of 50% RCA-50% NA with 0.11% SAP of the total cement mixture, while the second sample consisted of 50% RCA-50% NA with 0.3% SAP of the total cement mixture. Each case included 3 sample mixtures for Compressive and Flexural Tests conducted over 28 days. Thus, a total of 18 samples were tested. Initial studies on recycled concrete aggregate (RCA) by some established researchers reflected a maximum usage of only 30% when mixed with natural aggregate to create new concrete. Therefore, this study, which focused on increasing the percentage of RCA used in construction projects, aimed to contribute to addressing current environmental issues.

Data Gathering Procedure

a. Materials

The researchers used this study's materials: cement, sand, coarse and fine aggregates for RCA and NA, potable water, and super absorbent polymers from diapers or sanitary napkins. The Recycled Concrete Aggregate was all from the debris from demolished buildings of our university's College of Arts and Sciences and College of Fine Arts and Design. The RCA was manually crushed to remove the reinforcing steel bars and collect the coarse aggregate (sieved using a sieve retained No 41476mm)) and fine aggregates (weighing steeve passing No. 4 (476) to be used in the experiment. The SAP was extracted manually by ripping open the baby diapers and shaking them thoroughly inside a zip plastic bag and a plastic container to extract an amount of SAP.

b. Sample Preparation

Table 1 shows that 0.0063 kilograms (0.11%) of Super Absorbent Polymer was used with proportions of 50% Recycled Concrete Aggregates and 50% Natural Aggregates, and 0.017 kilograms (0.3%) of Super Absorbent Polymer was used for 50% Recycled Concrete Aggregates and 50% Natural Aggregates. The specific weight of the RCA was computed based on the percentage variance.

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Table 1
Proposed Mixture of Concrete for Compressive Strength

Sample	Design Mix (kg)						
	Cement	Sand		Gravel		SAP	Water
		50%RCA	50%NA	50%RCA	50%NA		
50% RCA + 50% NA + 0.11% SAP	5.724	6.483	6.483	13.36	13.36	0.0063	2.865
50% RCA + 50% NA + 0.3% SAP	5.724	6.483	6.483	13.36	13.36	0.017	2.865
Traditional Concrete	5.724	12.97		26.71		-	2.862

Table 2 shows that 0.0394 kilograms (0.3%) of Super Absorbent Polymer was used with proportions of 50% Recycled Concrete Aggregates (RCA) and 50% Natural Aggregates (NA), while 0.0144 kilograms (0.11%) of Super Absorbent Polymer was used for the 50% Recycled Concrete Aggregates and 50% Natural Aggregates mixture. The specific weight of the RCA was computed based on the percentage variance.

Table 2
Proposed Mixture of Concrete for Flexural Strength

Sample	Design Mix (kg)						
	Cement	Sand		Gravel		SAP	Water
		50%RCA	50%NA	50%RCA	50%NA		
50% RCA + 50% NA + 0.11% SAP	13.12	14.86	14.86	30.62	30.62	0.0144	6.56
50% RCA + 50% NA + 0.3% SAP	13.12	14.86	14.86	30.62	30.62	0.0394	6.56
Traditional Concrete	13.12	29.72		61.24		-	6.56

c. Procedure of Mixing Concrete

The researchers followed the traditional method outlined in the table for conventional concrete. A different mixing approach was used for the mixture containing recycled concrete aggregate (RCA). The researchers followed the Two-Stage Mixing Approach (TSMA) to achieve better results in the properties of the concrete. In the first stage, the coarse and fine aggregates were mixed for 60 seconds, and half of the water was added and mixed for another 60 seconds. The cement material was added and mixed in the second stage for 30 seconds. The remaining water was added and mixed in the third stage for 120 seconds.

d. Curing

To prevent the evaporation of water from the unhardened concrete, the specimens were immediately covered with a non-absorptive, non-reactive plate or sheet made of tough, durable, impervious plastic. The specimens were removed from the molds after 24 to 48 hours of casting. Unless otherwise specified, all specimens were moist cured at 23°C ± 2°C (73°F ± 3°F) from the time of molding until the moment of testing. Test specimens were always kept with free water on the entire surface area.

Data Analysis

After curing the specimens, the collected data for the compressive and flexural tests were analyzed, interpreted, and presented in tabular and graphical forms. A one-way analysis of variance (ANOVA) was conducted to determine if there was a significant difference between the different proportions of samples. The assumptions for the ANOVA analysis included that the distribution of the sample means was normally distributed, errors between cases were independent, outlying scores had been removed from the dataset, and the population variances across different levels of each independent variable were equal. The null hypothesis stated that the means at all levels were equal.

RESULTS AND DISCUSSIONS

This chapter presents the gathered data, the proportions of mixtures, the compressive and flexural test results, and the researcher's analysis and interpretation.

Weights of Samples with Properties of Aggregates

The proposed proportioning of the design mixture was redefined to meet the total volume of the mold. The proportioning was adjusted to 10% higher to ensure the samples would fill the mold prepared for the mixture. The following data presented were the actual proportions of the cement, sand, gravel, recycled concrete aggregates, and super absorbent polymers.

Actual Mixtures of Concrete for Compressive Test

The actual mixtures were adjusted to fill the three cylinders for each variance to avoid delay in the mixing process. The actual mixture proportions remained the same, but the volume of the mixtures was increased to ensure the actual mold volumes would be filled up. Class A (1:2-4) is the design mixture used for the three variances on the table. The adjustment of the total volume did not affect the design mixture due to the adjustment of the proportioning of the materials.

Table 3

Actual Mixtures of Concrete for Compressive Test

Sample	Design Mix (kg)						
	Cement	Sand		Gravel		SAP	Water
		50%RCA	50%NA	50%RCA	50%NA		
50% RCA + 50% NA + 0.11% SAP	6.3	7.13	7.13	14.69	14.69	0.0069	3.15
50% RCA + 50% NA + 0.3% SAP	6.3	7.13	7.13	14.69	14.69	0.0189	3.15
Traditional Concrete	6.3	14.267		29.39		-	3.15

Actual Mixture of Concrete for Flexural Strength

Table 4 presents the adjusted measurements of each material needed to prepare the concrete samples. The design mixtures were adjusted to fill the mold and avoid unnecessary delay in the mixture process.

On the Weight of Test Specimens

The weight of the samples was determined through the triple beam balance. The cylinder samples were weighed using the triple beam balance, and the rectangular specimens were weighed using another weighing scale.

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Table 4
Actual Mixture of Concrete for Flexural Strength

Sample	Design Mix (kg)						
	Cement	Sand		Gravel		SAP	Water
		50%RCA	50%NA	50%RCA	50%NA		
50% RCA + 50% NA + 0.11% SAP	14.43	16.34	16.34	33.68	33.68	0.0159	7.21
50% RCA + 50% NA + 0.3% SAP	14.43	16.34	16.34	33.68	33.68	0.043	7.21
Traditional Concrete	14.43	32.69		67.36		-	7.21

Weights of Test Specimens

Tables 5 and 6 show the weights of each treated and traditional concrete specimen. The average weights for each mixture were computed to define the approximate weight of the mixture. The 50% RCA + 50% NA + 0.11% SAP had the highest average weight. The table shows that the average weight of both treated concrete specimens increased when RCA and SAP were used, compared to the weight of conventional concrete.

Table 5
Weights of Test Specimens for Cylindrical Concrete

Sample	Sample No.	Weight (KG)	Average Weight (KG)
Traditional Concrete	1	12.75	12.77
	2	12.66	
	3	12.91	
50% RCA + 50% NA + 0.11% SAP	4	13.70	13.17
	5	13.20	
	6	12.60	
50% RCA + 50% NA + 0.3% SAP	7	13.08	12.87
	8	12.68	
	9	12.84	

Table 6
Weights of Test Specimens for Concrete Beam

Sample	Sample No.	Weight (KG)	Average Weight (KG)
Traditional Concrete	1	28	29.10
	2	30	
	3	29.30	
50% RCA + 50% NA + 0.11% SAP	4	30	30.57
	5	30.80	
	6	30.90	
50% RCA + 50% NA + 0.3% SAP	7	30.70	30.05
	8	29.80	
	9	31	

On the Analysis of Variance of Weights of the Different Treated Concrete and the Traditional Concrete

The following tables show the analysis of variance between the weights of the traditional concrete and the treated recycled concrete obtained with the data given in Table 7.

The analysis shows no significant difference in the weights of 50% RCA +50% NA+ 0.11% SAP. 50% RCA-50% NA 0.3% SAP and the Traditional Concrete, as shown by a computed F-value of 0.873 and p-value greater than 0.05. This implies that the weights of the concrete samples are the same regardless of the structure or mixture used.

Table 7
Summary of Analysis of Variance on the Weights of the Samples

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.449	2	8.724	.873	.465
Within Groups	59.993	6	9.999		
Total	77.442	8			

On the Flexural Strength of Concrete Beam Specimen

Table 8 presents the curing period in several days before the testing of the specimens that served as the basis for remarks on the flexural strengths of the traditional concrete and

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the treated concrete mixtures with proportions with 50% RCA, 50% NA with 0.11% SAP and 50% RCA, 50% NA with 0.3% SAP. The samples were tested at the Department of Public Works and Highways (DPWH), Bantay, Ilocos Sur.

Table 8 shows the number of days that the concrete samples will be prepared before testing the flexural strength.

Table 8

Number of Days Before the Flexural Testing

Sample	Sample Number	Date of Curing	Date at 28 days	Date Tested	No. of Days Before Testing
Traditional	1	03/16/2021	04/13/2021	04/13/2021	28
Concrete	2	03/16/2021	04/13/2021	04/13/2021	28
	3	03/16/2021	04/13/2021	04/13/2021	28
50%RCA +	4	03/16/2021	04/13/2021	04/13/2021	28
50%NA +	5	03/16/2021	04/13/2021	04/13/2021	28
0.11% SAP	6	03/16/2021	04/13/2021	04/13/2021	28
50%RCA +	7	03/16/2021	04/13/2021	04/13/2021	28
50%NA +	8	03/16/2021	04/13/2021	04/13/2021	28
0.3% SAP	9	03/16/2021	04/13/2021	04/13/2021	28

The series of dates indicated were the dates when the samples made were subjected to curing. It served as the basis of age in selecting designed flexural strength.

Table 9 shows the data gathered on the flexural strength of the concrete beam samples, design flexural strength, and the remarks of each cottiers beam samples.

The data under the column shows the results for the flexural strength of concrete samples. In contrast, the data under the column design states the allowable flexural strength that the sample must have. Table 9 shows an increase in the flexural strength of concrete as more SAP was added to the concrete. Though test specimens were tested later than 14 days, studies from the National Ready Mix Concrete Association showed that the flexural strength of concrete decreases as the concrete dries. Therefore, the researchers accepted the results.

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Table 9

Flexural Strength of Concrete Beam Sample

Sample	Sample No.	ACTUAL		DESIGN	Remarks
		Flexural Strength (MPa)	Days Old	Flexural Strength (MPa)	
Traditional Concrete	1	3.21	28	3.5	Failed
	2	4.16	28	3.5	Passed
	3	4.13	28	3.5	Passed
50% RCA + 50% NA + 0.11% SAP	4	3.48	28	3.5	Passed
	5	3.42	28	3.5	Passed
	6	3.28	28	3.5	Passed
50% RCA + 50% NA + 0.3% SAP	7	3.64	28	3.5	Passed
	8	4.28	28	3.5	Passed
	9	3.83	28	3.5	Passed

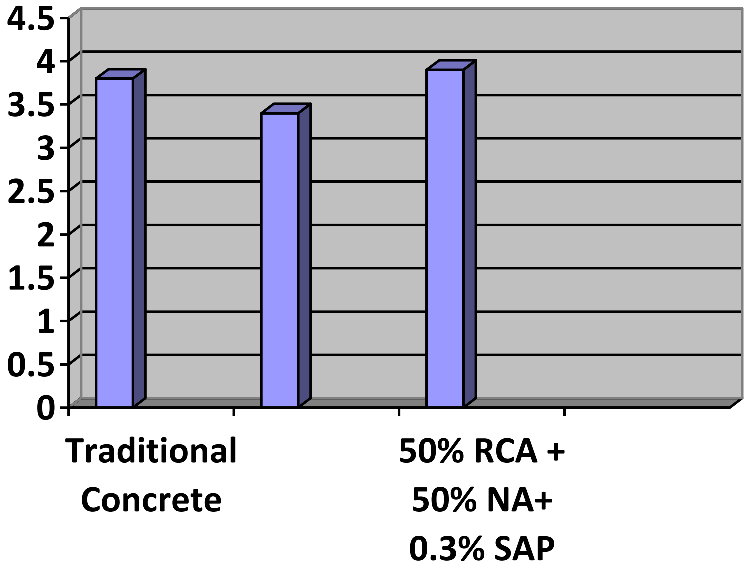

Figure 2

Average flexural strength of the concrete mixture

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On the Analysis of Variance of Flexural Strength of the Different Treated Recycled Concrete and the Traditional Concrete

The following tables show the results of the analysis of variance between the weights of the traditional concrete and the reconstituted concrete obtained with the data given in Table 9 under the column for the actual flexural strength with rows for treated recycled concrete mixture.

Table 10 compares the concrete products in three structures and serves as the basis for remarks on the different samples.

Table 10

Summary of Analysis of Variance of the Flexural Strength of the Concrete Products

Source of variation	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	.888	2	.444	1.158	0.376
Within Groups	2.300	6	.383		
Total	3.188	8			

Table 10 shows no significant difference in their flexural strength with F=1.158, p>0.05. This implies that concrete products with different structures have the same flexural strength.

On the Compressive Strength of Cylindrical Test Specimens

Table 11 presents the number of days needed for curing before testing the specimens that served as the basis for remarks for the different samples of treated recycled concrete with the proportions of 50%RCA,50%NA with 0.11%SAP: 50% RCA,50% NA with 0.3% SAP. The samples were tested at the Material Testing Laboratory, the Department of Public Works and Highways (DPWH), Bantay, Ilocos Sur.

The series of dates indicated were when the samples were subjected to curing. It served as the basis of age in selecting designed compressive strength.

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Table 11
Number of Days Before the Compressive Test

Proportion	Sample	ACTUAL			DESIGN			Remarks
		Maximum Load (Kn)	Compressive Strength (MPa)	Day Old	Age	Max Compressive Strength (2500 psi) psi	(MPa)	
Traditional Concrete	1	306.4	16.7	28	45	2500	17.24	Passed
	2	377.5	20.6	28	45	2500	17.24	Passed
	3	358.2	19.6	28	45	2500	17.24	Passed
50% RCA + 50% NA + 0.11% SAP	4	194.7	10.6	28	45	2500	17.24	Failed
	5	220.9	12.1	28	45	2500	17.24	Failed
	6	257.4	14.1	28	45	2500	17.24	Failed
50% RCA + 50% NA + 0.3% SAP	7	535.7	29.3	28	45	2500	17.24	Passed
	8	398.4	21.8	28	45	2500	17.24	Passed
	9	477.0	26.1	28	45	2500	17.24	Passed

Table 12 shows the data gathered on the flexural strength of the concrete beam samples, design compressive strength, and the remarks of each concrete beam sample.

The "Days Old" column refers to the days before testing. At the same time, "Age" is according to the DPWH specification, which serves as the basis for the maximum compressive strength allowable as indicated in the specification and the 2500 psi required for structural concrete.

The results showed that samples with a lower percentage of SAP failed. Relative to the study of Anbhule Sachin (2017), he found that an increase in compressive strength is observed with the increase in the percentage of SAP from 0.15% to 0.30%. The data for the treated recycled concrete from DPWH were consistent; thus, the apparatus or the UTM was well operating and maintained.

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Table 12
Compressive Strength of Cylindrical Test Specimens

Proportion	Sample	ACTUAL				DESIGN		Remarks
		Maximum Load (Kn)	Compressive Strength (MPa)	Day Old	Age	Max Compressive Strength (2500 psi)		
						psi	(MPa)	
Traditional Concrete	1	306.4	16.7	28	45	2500	17.24	Passed
	2	377.5	20.6	28	45	2500	17.24	Passed
	3	358.2	19.6	28	45	2500	17.24	Passed
50% RCA + 50% NA + 0.11% SAP	4	194.7	10.6	28	45	2500	17.24	Failed
	5	220.9	12.1	28	45	2500	17.24	Failed
	6	257.4	14.1	28	45	2500	17.24	Failed
50% RCA + 50% NA + 0.3% SAP	7	535.7	29.3	28	45	2500	17.24	Passed
	8	398.4	21.8	28	45	2500	17.24	Passed
	9	477.0	26.1	28	45	2500	17.24	Passed

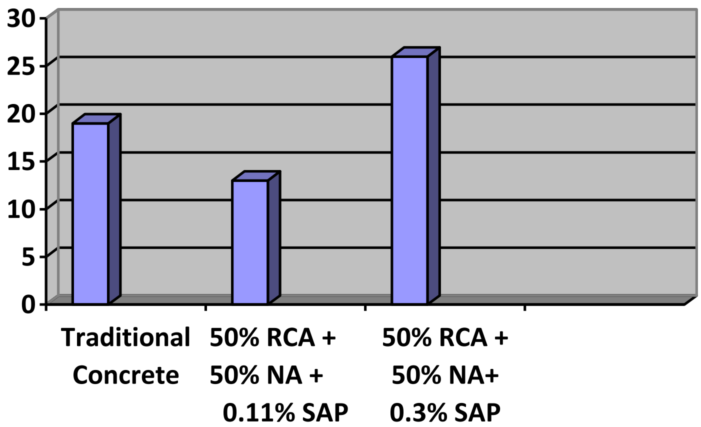

Figure 3
Average compressive strength of concrete mixture

Figure 3 shows the treated recycled concrete's average compressive strength and the traditional concrete's compressive strength.

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On the Analysis of Variance of the Compressive Strength of the Treated Recycled Concrete and the Traditional Concrete

The following tables show the results of the analysis of variance between the compressive strength of the traditional concrete and the treated recycled concrete obtained with the data given by Table 12 under the column of the compressive strength.

Analysis of Variance for the Compressive Strength of the Treated Recycled Concrete and the Traditional Concrete

Table 13 Summary of Analysis of Variance of the Compressive Strength of the Concrete Products.

Table 13

Summary of Analysis of Variance of the Compressive Strength of the Concrete Products

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	272.029	2	136.014	19.112	.002
Within Groups	42.700	6	7.117		
Total	314.729	8			

Table 13 shows a significant difference in the compressive strength of the concrete products between and among the three structures or mixtures with F=19.112, p<0.05. This implies that using a particular mixture significantly contributes to the compressive strength of concrete products by using a particular structure or mixture.

To determine which of these structures or mixtures yields a significant difference (Least square difference), LSD was used for multiple comparisons. The result is shown below:

Table 14

Pairwise Comparison of the Compressive Strength of the Recycled Concrete Samples

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	272.029	2	136.014	19.112	.002
Within Groups	42.700	6	7.117		
Total	314.729	8			

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Summary of Analysis of Variance of the Compressive Strength of the Concrete Products

Table 14 shows that all three comparison pairs yielded a significant difference in their compressive strength. The concrete using a traditional mixture has a significantly higher compressive strength than 50% RCA + 50% NA +0.11% SAP with a mean difference of 6.7000 MPa. On the other hand, concrete products using 50% RCA +50% NA +0.3% SAP have significantly higher compressive strength than those using traditional mixtures, with a mean difference of 6.76667. Hence, the compressive strength of concrete products using 50% RCA + 50% NA +0.3% SAP is advisable.

Moreover, a comparison between the compressive strength between the use of 50% RCA +50% NA +0.11% SAP and 50% RCA +50% NA +0.3% SAP yields a significant difference with a mean difference of -13.46667 MPa, $p<0.05$. This implies that the compressive strength of the concrete products using 50% RCA + 50% NA + 0.3% SAP is significantly higher by 13.46667 MPa than 50% RCA + 50% NA+0.11% SAP. Hence, it is better to produce concrete using 50% RCA + 50% NA +0.3% SAP than using 50% RCA +50% NA +0.11% SAP.

CONCLUSIONS

The study highlighted the potential of using recycled concrete aggregates (RCA) and Super Absorbent Polymers (SAP) in sustainable construction. It found that SAP improves the flexural strength of RCA-based concrete, with higher SAP percentages yielding better results. Conversely, lower SAP percentages reduce compressive strength, likely due to insufficient compensation for RCA's weaker properties. The two-stage mixing approach demonstrated the feasibility of using up to 50% RCA for structural concrete applications. While RCA reduces landfill waste and the demand for virgin aggregates, it requires energy-intensive processing. SAP enhances durability and reduces maintenance needs but is costly and depends on non-renewable resources. RCA and SAP promote resource efficiency and durability in concrete structures, contributing to sustainable construction goals. However, successful adoption requires optimized RCA processing, reliable SAP sourcing, and localized implementation strategies.

RECOMMENDATIONS

Based on the findings and conclusions, the researchers recommend exploring advanced admixtures such as silica fume, fly ash, superplasticizers, or polymers like styrene-butadiene rubber (SBR) to enhance the strength, durability, and workability of RCA-based concrete. They suggest investigating the long-term performance of RCA-based concrete, including freeze-thaw resistance, shrinkage behavior, sulfate resistance, and carbonation resistance, to ensure durability under various environmental conditions. Optimizing mix designs for RCA content exceeding 30% is recommended, considering its high-water absorption and using pre-saturation techniques or admixtures to mitigate potential adverse effects. The researchers also recommend identifying reliable bulk suppliers for SAP and analyzing its cost-effectiveness for large-scale construction applications. Investing in crushing machinery to produce high-quality RCA for construction projects efficiently is advised. Additionally, conducting microstructural analysis, field tests, and life-cycle assessments is necessary to validate findings and further promote the sustainability of RCA-based concrete in construction.

ETHICAL STATEMENT

The content presented in this study is the writers' unique report based on existing studies. No other publications are considering publishing the paper, and have never been submitted to any reputed journal or publisher. The study accurately and thoroughly covers the writers' investigation and analysis.

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