COCOCANE: THE EFFECTS OF SUGARCANE BAGASSE ASH AND COCONUT COIR ASH AS PARTIAL CEMENT REPLACEMENT ON THE WORKABILITY AND STRENGTH OF CONCRETE

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ABSTRACT

This study assessed the sustainability of partially replacing coconut coir ash (CCA) and sugarcane bagasse ash (SCBA) for ordinary Portland cement (OPC) in concrete. SCBA and CCA provide a sustainable replacement that lessens dependence on non-renewable resources and encourages ecologically friendly construction methods in the Philippines. The study evaluated the impact of 5%, 15%, and 25% ash replacement on concrete performance using a factorial design. For 28 days, 45 cylinders with a 1:2:4 mix ratio underwent curing. The results indicated that as the ash content of concrete increased, its workability improved. The slump values varied from 25.4 mm to 120 mm at 5% replacement, 30 mm to 105 mm at 15%, and 76.2 mm to 127 mm at 25%. The increased slump at higher replacement levels suggests better flowability, attributable to the finer particles and pozzolanic character of the added ash components. The control mix obtained a compressive strength of 15.58 MPa. The highest compressive strength, 18.30 MPa, was recorded at 5% replacement with 100% SCBA, exceeding the control mix. While compressive strength generally declined as CCA level and replacement levels increased, it dropped significantly to 4.84 MPa when 25% CCA was used without SCBA. The influence of ash type and ash quantity on performance was highlighted by statistical analysis, which indicates significant differences across mixtures. This highlights SCBA's more consistent and effective pozzolanic performance.

Keywords: Sugarcane Bagasse Ash (SCBA), Coconut Coir Ash (CCA), Partial Replacement, and Compressive Strength

INTRODUCTION

Among the sectors of the global economy expanding the fastest is the construction industry. The Philippine construction industry achieved an annual growth rate of 9.2% in 2022 and is expected to continue growing, according to the Philippine Statistics Authority. It is widely recognized that the building sector consumes more raw materials, leading to a scarcity of natural resources and adverse environmental impacts (Kukah et al., 2022). In this industry, concrete is the most often utilized man-made construction material and plays a fundamental role. Many natural resources are used in the production of concrete. Given the current situation, it is well recognized that natural resources are running out globally while industrial waste production is also rising significantly (Venu, D. 2016).

In addition, non-renewable resources such as limestone are being depleted due to increased exploitation of raw materials to support expanded cement production. Pollutants such as dust, noise, and greenhouse gases, mostly carbon dioxide (CO_2), are emitted into the environment when these materials are processed in manufacturing facilities, worsening climate change and causing environmental degradation (Mohammad, N. 2022).

Furthermore, about 0.139 kg of oil is used to produce 1 kg of cement, further depleting fossil fuel supplies. The substantial release of carbon dioxide (CO_2) during the production of ordinary Portland Cement (OPC) is a significant environmental concern. Cement manufacture is one of the main causes of climate change, accounting for around 8% of global CO_2 emissions.

This happens because extremely high temperatures applied to raw materials like limestone cause CO2 to be released.

Building on the UN Sustainable Development Goals, the researchers investigated various approaches to reduce pollution from cement production. The SDGs emphasize the value of sustainable infrastructure and encourage the building sector to search for environmentally friendly substitutes. In this instance, the study aimed to identify alternatives to cement that reduce its environmental impact while maintaining the strength and durability required for modern infrastructure.

Sugarcane Bagasse Ash

The byproduct of the production of sugar and alcohol, sugar cane bagasse ash (SCBA), is one alternative pozzolanic ingredient that can be mixed with Portland cement. An industrial byproduct known as SCBA is produced in sugar mills during sugarcane processing, leaving behind bagasse, a large, fibrous waste product. When bagasse is burned at a specific temperature, a large amount of ash, known as sugarcane bagasse ash, is produced. (M. Khalil et al. 2020).

Figure 1
Sugarcane Bagasse

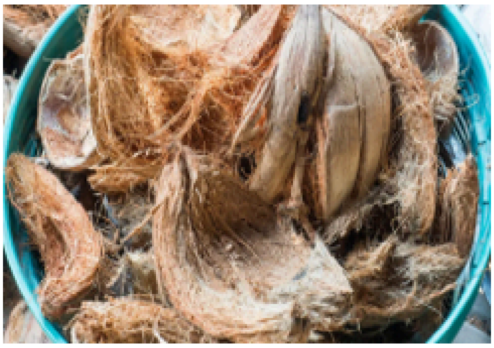
Source: *https://www.dreamstime.com/stock-photo-sugarcane-bagasse-nature-fiber-recycle-biofuel-pulp-building-materials-image88131160*

The Philippines was predicted to produce 21.65 million metric tons of sugarcane in 2023 (Balita, C., 2024). Central Azucarera de Tarlac is a fully integrated sugar-processing facility headquartered in Tarlac province. It produces a variety of goods, including raw and refined sugar. In addition to sugar, the plant also produces alcohol, liquid carbon dioxide, and yeast, making it a versatile operation within the sugar industry. This facility plays a crucial role in the local economy by providing a range of essential products derived from sugarcane processing. It has been reported that for every unit of bagasse, the volume of ash produced is roughly 8% of the original bagasse volume. This phenomenon leads to the accumulation of a considerable quantity of SCBA, which can occupy significant physical space.

Figure 2
Sugarcane Bagasse Ash

Source: *https://www.researchgate.net/figure/Sugarcane-bagasse-ash-Mangi-etal11addresses-the-suitability-of-sugarcane-bagasse-ash_fig2_371594915*

Figure 3
Coconut Coir



Source: *https://www.gardeningknowhow.com/gardening-pros-cons/coconut-coir-pros-and-cons*

Coconut coir is a hard and durable biodegradable lignin fiber generated from the fibrous mesocarp of coconut fruits, comprising around 25% of the nut. Coir can be used interchangeably with coir pith and is also known as coir peat, coir dust, coir meal, or coco peat (Editor, 2022). Coconut coir ash (CCA) is produced through the coconut coir manufacturing process. In the Philippines, the coconut industry plays a vital role in agriculture. Of the country's 82 provinces, 69 cultivate coconuts, covering 3.62 million hectares and providing jobs for around 2.5 million farmers.

Kumar et al. (2024) argued that the utilization of these natural materials, such as coconut coir ash, promotes sustainable construction practices by decreasing dependence on non-renewable resources and mitigating the environmental impact of construction activities. To reduce environmental damage caused by agricultural and industrial waste products, such as coconut coir ash, which are byproducts of the agricultural sector, using them in concrete not only increases the material's strength but also ensures proper disposal, lessening their environmental impact.

Figure 4
Coconut Coir Ash

Source: *https://www.semanticscholar.org/paper/Development-and-Performance-Evaluation-of-Coir-Pith-Venugopal-Sambamurthy/63fa0c4d8a3c42c0e016f583b12e65007be80fc3*

The chemical components of Ordinary Portland Cement (OPC), Coconut Pith Ash (CPA), and Sugarcane Bagasse Ash (SCBA) are contrasted in the table below.

Table 1
Chemical components of Ordinary Portland Cement (OPC), Coconut Pith Ash (CPA), and Sugarcane Bagasse Ash (SCBA)

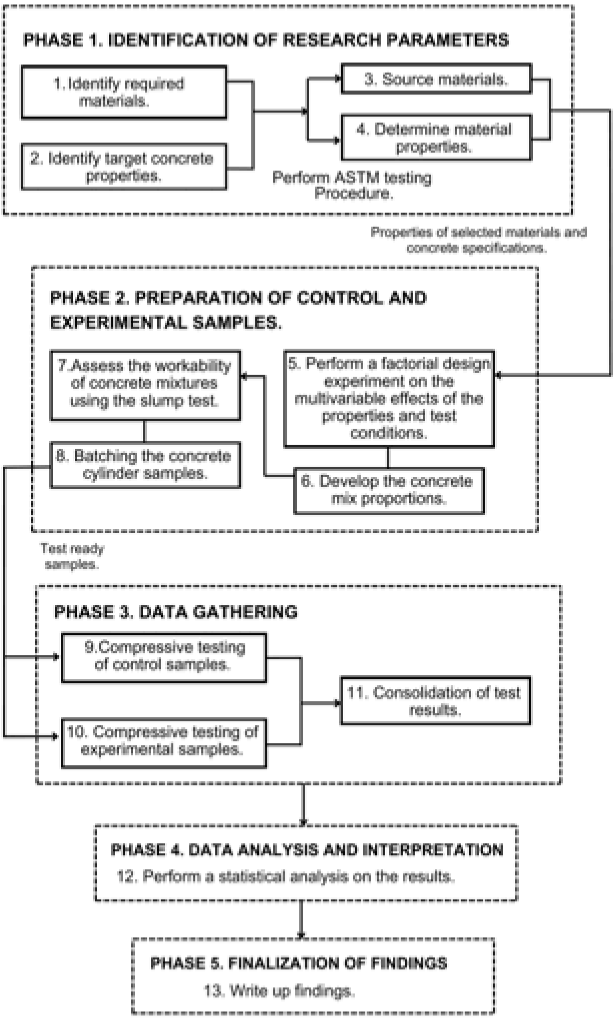
CHEMICAL COMPOSITION	CPA (%)	SBCA (%)	OPC (%)
CaO	16.4	11.8	66.8
SiO_2	34.50	62.43	18.4
Al_2O_3	01.35	4.38	5.6
Fe_2O_3	02.22	6.98	3
MgO	02.07	2.51	1.4
SO_3		1.48	2.8
KCI	26.48		0.5

Given the available information, using mineral admixtures in concrete as a partial substitute for cement is an efficient way to reduce environmental impact. This can result in cost savings, energy conservation, and reduced waste emissions. Although the weight percentages of each chemical are not the same, SCBA and CCA share the same characteristics as OPC, which are necessary for binding. These factors led researchers to replace some of the cement with SCBA and CCA.

Conceptual Framework

The study's conceptual framework was structured through the identification of research parameters, in which initial concepts and potential variables were defined to establish the study's direction. Controlled and experimental samples were then prepared using raw materials such as SCBA from Tarlac, CCA from Bagabag, and aggregates from Nueva Vizcaya. These samples were tested at the Regional Satellite Materials Testing Laboratory, and data were systematically gathered. The collected data were analyzed and interpreted to assess the impact of the variables. The process concluded with the consolidation of results and finalization of key findings that shaped the study's conclusions.

Figure 5
Conceptual Framework



METHODOLOGY

A. Research Design

This study employed a factorial design for its experiment. It involved two or more independent variables: sugarcane bagasse ash and coconut coir ash. The data collection in the factorial design of the experiment enabled researchers to examine the influence of numerous factors on a dependent variable, both individually and collectively. The study complied with the ASTM International standard testing protocols for civil engineering materials.

B. Research Locale

The sugarcane bagasse ash (SCBA) used in this study was sourced from Central Azucarera de Tarlac in San Miguel, Tarlac City, Tarlac. Coconut coir ash (CCA) was collected from various locations in Bagabag, Nueva Vizcaya. Additional materials, such as cement, water, and fine and coarse aggregates, were purchased from nearby suppliers in Bayombong, Nueva Vizcaya. Testing was done at the DPWH Regional Satellite Materials Testing Laboratory, while sample preparation was performed at Masoc, Bayombong. For 28 days, the concrete cylinder samples to be tested for compressive strength were cured.

C. Research Participants

The participants in this study included the researchers, who investigated sugarcane bagasse ash (SCBA) and coconut coir ash (CCA) as partial substitutes for cement in concrete production. Assessing how these agricultural wastes affected the workability and compressive strength of concrete mixtures was their main responsibility.

Additionally, the researchers worked with two materials testing facilities: the Saint Mary's University Construction and Testing Materials Laboratory and the DPWH Regional Satellite Materials Testing Laboratory. These institutions helped assess the physical characteristics of the SCBA and CCA utilized in the mixes, as well as the concrete's workability and compressive strength.

D. Research Instruments

The instruments used in this study included a compression machine, a digital weighing scale, and standard test sieves. The compression machine was utilized to apply compressive force to concrete samples in cube or cylinder form to assess their strength under crushing loads. A digital weighing scale was used to accurately measure the mass of the materials for the concrete mix. Standard test sieves, composed of woven-wire mesh within cylindrical frames, were used to determine the particle-size distribution of the aggregates.

E. Research Materials

The following materials were used in the study:

The materials used in this study included aggregates, sugarcane bagasse ash, coconut coir ash, Ordinary Portland Cement (OPC), and water. Coarse and fine aggregates, sourced from the Magat River, consist of crushed rock, sand, and gravel, with classification based on particle size—sand as fine aggregate and gravel as coarse. Sugarcane bagasse ash, an industrial byproduct, was obtained from Sugarcane Mills in Central Azucarera de Tarlac, San Miguel, Tarlac City, while coconut coir ash, a result of the calcination process, was sourced from Bagabag, Nueva Vizcaya. Ordinary Portland Cement (Republic-type IT mixed) was used as the primary binding agent and was supplied by New Remington in Bayombong, Nueva Vizcaya. Lastly, water served as a vital component for mixing, curing, and preparing concrete and mortar throughout the experimentation.

F. Data Gathering Procedure

Two sets of continuous data were collected for this study. The proportions of the design mix and the percentages of sugarcane bagasse ash and coconut coir ash used as partial cement substitutes were among the input data included in the first set. The ASTM design mix rules were used to calculate these values, and previous study material was consulted for evaluation. The second set of data focused on the concrete's workability and compressive strength. The concrete's resistance to compressive forces was evaluated by measuring its compressive strength using a Compression Machine in accordance with ASTM C39. Additionally, workability was evaluated using the slump test, per ASTM C143, to ensure the concrete mix reaches the appropriate consistency for handling and application in practical situations.

Phase 1: Identification of Research Parameters

This phase of the study focused on gathering the necessary materials—cement, aggregates, water, superplasticizer, sugarcane bagasse ash, and coconut coir ash—and establishing the parameters for both experimental and control concrete samples. Researchers first identified the required materials using references from books, online sources, and professional experience, organizing the list in Microsoft Excel. They then determined the target compressive strength of the concrete cylinders using MATLAB and Excel to analyze data from various references. Materials were sourced from local suppliers, with sugarcane bagasse ash obtained from Central Azucarera de Tarlac and coconut coir ash from Bagabag, Nueva Vizcaya. To determine the properties of the ashes, tests such as normal consistency of cement paste, setting time, specific gravity, and density were conducted at the Regional Satellite Materials Testing Laboratory, and the results were organized using Excel.

Phase 2: Preparation of control and experimental samples

In this phase of the study, the researchers developed suitable concrete mix proportions. They identified key independent variables—specifically the percentages of sugarcane bagasse ash (SCBA) and coconut coir ash (CCA) at 5%, 15%, and 25%—to form a comprehensive matrix of experimental setups, organized in an Excel spreadsheet. Based on the finalized design mix, the necessary number of concrete cylinder samples was prepared. The workability of each mix was assessed using the slump test, with higher slump values indicating greater flowability. Concrete batching was conducted in Masoc, Bayombong, Nueva Vizcaya, and a total of 45 experimental samples and three control samples were cast. All samples intended for compressive strength testing were cured for 28 days in a full-submersion water tank.

Phase 3. Data Gathering

During this stage, the researchers conducted compressive strength testing on both control and experimental concrete cylinders in accordance with ASTM C39 to ensure consistency and structural integrity. The control samples were tested at the DPWH Regional Satellite Materials Testing Laboratory using a compression machine, providing baseline compressive strength values. Experimental samples underwent the same evaluation process. All test results were compiled and consolidated into an organized Excel table, along with the Phase 2 data matrix, to facilitate comparison and analysis.

Phase 4: Data analysis and interpretation

The researchers used the structured data from Phase 3 to conduct a factorial design of experiments (DOE), using the design mix proportions and percentages of sugarcane bagasse ash (SCBA) and coconut coir ash (CCA) as input variables, and the resulting compressive strength of concrete as the output. This experimental design allowed them to analyze the individual and combined effects of multiple factors on compressive strength, as well as explore the relationships between these variables and the mix proportions.

Phase 5. Finalization of Findings

The researchers wrote and compiled the entire data report for the study.

G. Statistical Treatment of Data

Before statistical analyses were conducted, the data were thoroughly cleaned to guarantee accuracy and reliability.

The study used several advanced statistical methods, including Response Surface Methodology (RSM), Post Hoc Tests, Regression Analysis, and Analysis of Variance (ANOVA), to examine the relationships and interactions among variables. In particular, using different percentages of sugarcane bagasse ash and coconut coir ash as partial cement substitutes, ANOVA was used to determine whether there were statistically significant differences between group averages. Since the ANOVA results did not indicate which differences between pairs of means were significant, a post hoc test was used. It examined variations in the means across several groups while controlling the error rate in each experiment.

Regression analysis was essential for determining the relationships between dependent variables, such as compressive strength, and independent factors, such as mix proportions and material percentages. This method measured how strong these relationships were and in which way they were. Furthermore, the experimental design was optimized using Response Surface Methodology (RSM), which investigated the relationships among variables and established the optimal mix proportions to achieve desired concrete qualities.

Matlab was employed for the three-dimensional (3D) creation and visualization of the Response Surface Methodology (RSM) models. The software generated surface and contour plots that illustrated the interaction effects between the independent variables, such as varying proportions of sugarcane bagasse ash and coconut coir ash. These three-dimensional diagrams gave a clear and comprehensive picture of how various factor combinations affected the response variables. The study improved the clarity and depth of the statistical interpretation by efficiently analyzing and presenting the RSM optimization results using MATLAB's graphical and computational capabilities.

RESULTS AND DISCUSSION

Results

A. Ash Properties

The physical properties of concrete mixtures with varying cement replacement levels (5%, 15%, and 25%) using coconut coir ash (CCA) and sugarcane bagasse ash (SCBA) were examined. Results showed a progressive delay in both initial and final setting times as ash content increased, attributed to the lower early-age reactivity of the ash compared to ordinary Portland cement (OPC). Specifically, the initial setting time extended from 135 minutes (5%) to 180 minutes (25%), while the final setting time ranged from 165 to 210 minutes. These delays are advantageous for improving workability, particularly in warm weather. Specific gravity values showed minor fluctuations, ranging from 2.6087 to 2.8986, indicating that ash incorporation did not significantly affect the mixture's compactness. However, density decreased consistently—from 1250 kg/m^3 at 5% replacement to 1052.63 kg/m^3 at 25%—signifying the production of lighter concrete mixtures. These changes in setting time and density were critical to evaluating both constructability and performance longevity.

B. Workability Test

The slump test was performed to assess the workability of concrete mixtures with various ash replacement levels. The results indicated that both ash content and water ratio directly influenced slump values. The highest workability was observed in the 25% replacement group, with a 30% increase in water content, resulting in slump values of 76.2-127 mm. The 15% replacement group, with a 25% increase in water, achieved slump values ranging from 30 mm to 105 mm. Meanwhile, the 5% replacement group with a 23% increase in water showed a wider range, from 25.4 mm to 120 mm. The control sample, containing no ash, exhibited a slump value of 50.8 mm.

Table 2
Attained Ash Properties

% Replacement	Initial Setting Time in minutes	Final Setting Time in minutes	Specific Gravity	Density in kg/m^3
5 %	135	165	2.8986	1250
15%	159	177	2.6087	1111.1111
25%	180	210	2.7523	1052.6316

These results suggest that combining higher ash replacement with adequate water adjustment can improve the mix's fluidity, which is essential for ease of placement and compaction, even if it does not directly reflect strength performance.

C. Compressive Strength and Compressive Strength

The compressive strength of concrete cylinders with varying replacement levels of CCA and SCBA was measured at 28 days. Results showed that mixtures with lower replacement percentages had higher strength than those with higher replacement percentages. In Group 1 (100% CCA), the 5% mix achieved 9.57 MPa, while 15% and 25% yielded 12.91 MPa and 4.99 MPa, respectively. The highest recorded strength across all groups was 18.89 MPa (5% replacement in Group 5: 100% SCBA), exceeding even the control mix (16.08 MPa). Conversely, the lowest strength was 4.99 MPa in the 25% replacement of Group 1. Overall, results indicated that moderate substitution levels (5% to 15%) produced favorable strength outcomes, while excessive substitution led to strength reduction. This suggests a limit to the effective percentage of ash replacement for structural applications.

Table 3
Slump Test

Sample		Slump Value (mm)
Control		50.8
5%	A1	25.4
	A2	25.4
	A3	40
	A4	60
	A5	120
15%	B1	40
	B2	30
	B3	30
	B4	100
	B5	105
25%	C1	76.2
	C2	88.9
	C3	101.6
	C4	114.3
	C5	127

Table 4
Summary of Results

Sample		Slump Value (mm)	Average Maximum Load (kN)	Average Strength (MPA)
Control		50.8	126.3	16.08
5%	A1	25.4	75.17	9.57
	A2	25.4	117.13	14.91
	A3	40	86.53	11.02
	A4	60	111.17	14.15
	A5	120	148.33	18.89
15%	B1	40	101.43	12.91
	B2	30	107.83	13.73
	B3	30	128.47	16.36
	B4	100	106.93	13.62
	B5	105	94.53	12.04
25%	C1	76.2	39.2	4.99
	C2	88.9	59.6	7.59
	C3	101.6	68.23	8.69
	C4	114.3	67.7	8.62
	C5	127	68.93	8.78

D. ANOVA and Post Hoc Analysis

Statistical comparisons using One-Way ANOVA tested the significance of differences in compressive strength across groups. In Group 1 (100% CCA), the p-value was 0.0117, indicating a statistically significant difference between replacement levels and the control. Tukey HSD revealed that C1 (25%) and Control differed significantly in strength. Group 5 (100% SCBA) also showed significant variance (p = 0.0143), especially between C5 and Control. However, Groups 2 (75% CCA–25% SCBA), 3 (50%- 50%), and 4 (25% CCA–75% SCBA) had p-values of 0.0601, 0.0526, and 0.0943, respectively, all of which exceeded the 0.05 threshold. These results indicate that only certain ash combinations (particularly those using 100% of either CCA or SCBA) cause notable variations in strength, while mixed proportions show less pronounced effects.

Figure 6
2D Model for Group 1 (0% SCBA - 100% CCA) using ANOVA Test

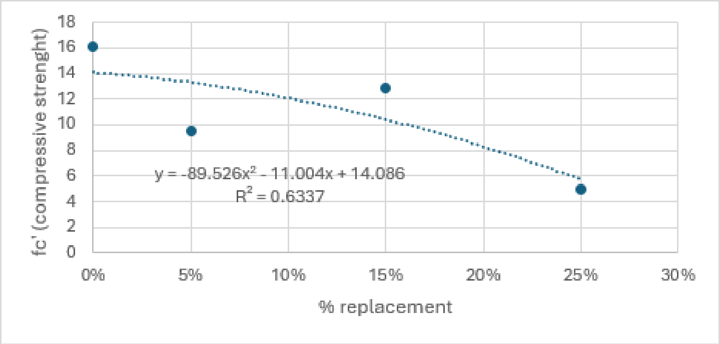


Figure 7

2D Model for Group 2 (25% SCBA - 75% CCA) using ANOVA Test

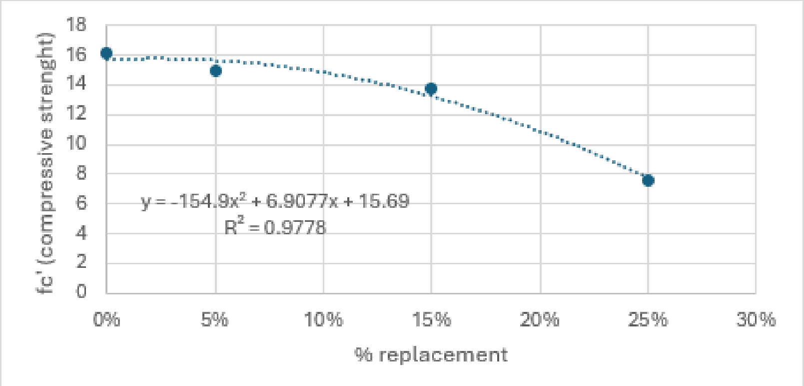


Figure 8

2D Model for Group 3 (50% SCBA - 50% CCA) using ANOVA Test

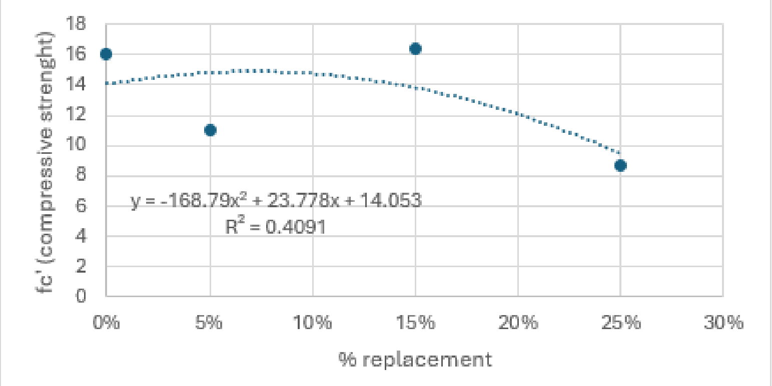


Figure 9

2D Model for Group 4 (75% SCBA - 25% CCA) using ANOVA Test

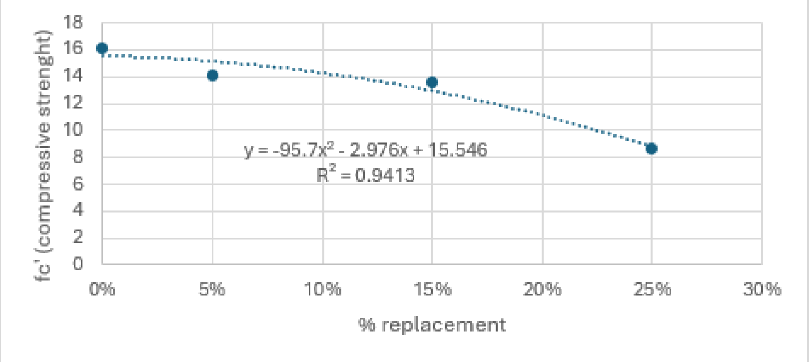
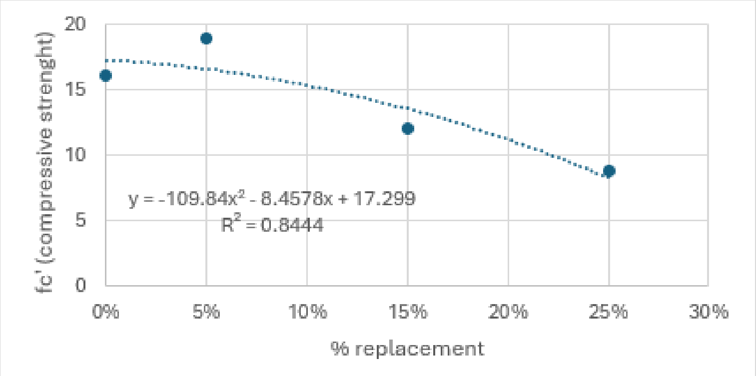


Figure 10

2D Model for Group 5 (100% SCBA - 0% CCA) using ANOVA Test



E. Regression Analysis

Regression analysis was used to examine the relationship between percentage replacement and compressive strength for each group. Group 1 (100% CCA) exhibited a statistically significant relationship with a p-value of 0.0173 and an R^2 of 0.4476, indicating that 44.76% of strength variation was explained by replacement level. Similarly, Group 2 (75% CCA – 25% SCBA) had a p-value of 0.0135 and $R^2 = 0.4723$. Group 4 (25% CCA – 75% SCBA) also showed significant results ($p = 0.0084$, $R^2 = 0.5160$). Group 5 (100% SCBA) had the strongest correlation with a p-value of 0.0040 and $R^2 = 0.5791$. In contrast, Group 3 (50%-50%) was not significant ($p = 0.1723$, $R^2 = 0.1784$). These results confirm that strength generally decreases with increasing replacement, and SCBA tends to yield more predictable outcomes than CCA when used alone.

Figure 11

2D Model for Group 1 (100% CCA – 0% SCBA) using Regression Analysis

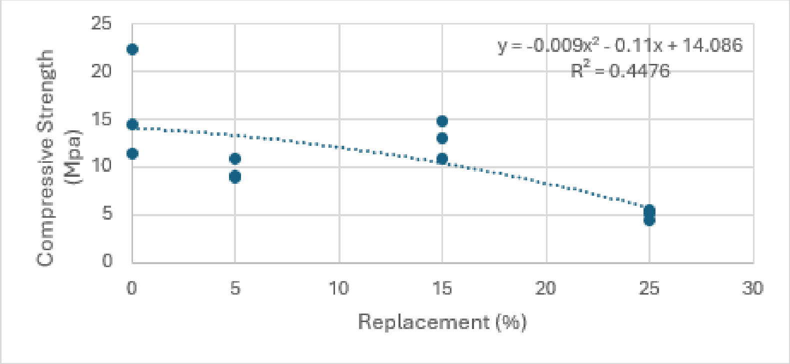


Figure 12

2D Model for Group 2 (75% CCA-25% SCBA) using Regression Analysis

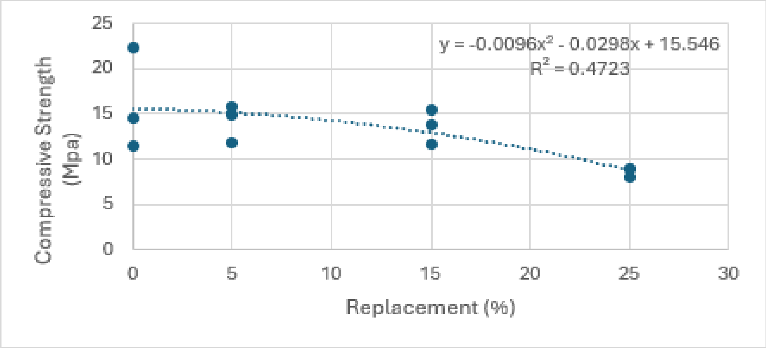
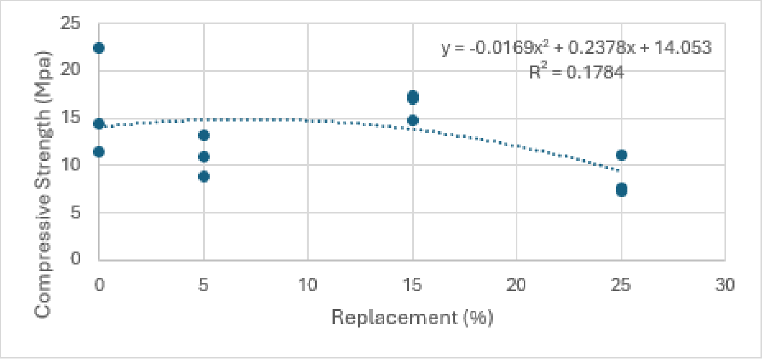


Figure 13

2D Model for Group 3 (50% SCBA-50% CCA) using Regression Analysis



F. Response Surface Methodology (RSM)

The Response Surface Methodology (RSM) was employed to model the combined effects of SCBA and CCA on compressive strength at 5%, 15%, and 25% cement replacement levels. The model for 25% replacement was statistically significant ($p = 0.0065$) with the highest R^2 value (0.9967), indicating an excellent fit. The 5% and 15% models also showed high R^2 values (0.9790 and 0.9904, respectively), though their p-values (0.2432 and 0.1656) were not statistically significant. The 3D surface plots revealed that optimal compressive strength occurred at high SCBA and moderate CCA ratios. Excessive CCA content or very low SCBA levels tended to reduce strength. Predicted values closely matched the actual test results, with minor discrepancies of less than 0.5 MPa, validating the model's accuracy. This confirms that RSM is an effective tool for optimizing mix proportions in sustainable concrete design using agricultural waste.

Figure 14

2D Model for Group 4 (25% CCA – 75% SCBA) using Regression Analysis

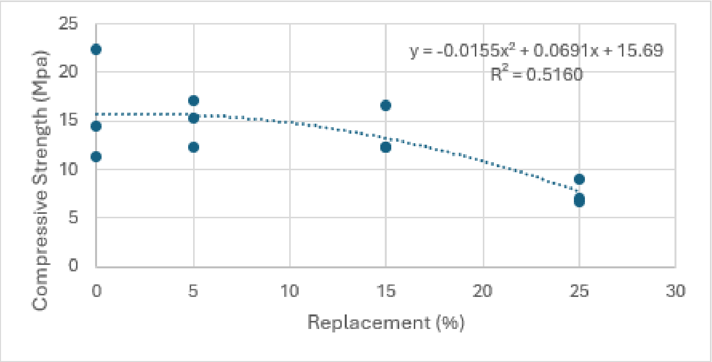


Figure 15

2D Model for Group 5 (0% CCA-100% CCA) using Regression Analysis

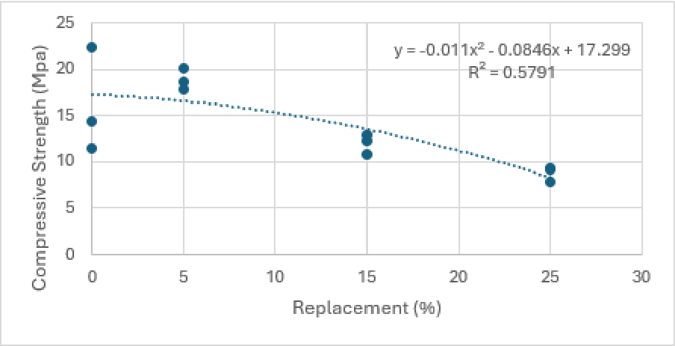


Figure 16

3D Model for 5% Cement Replacement using Response Surface Methodology

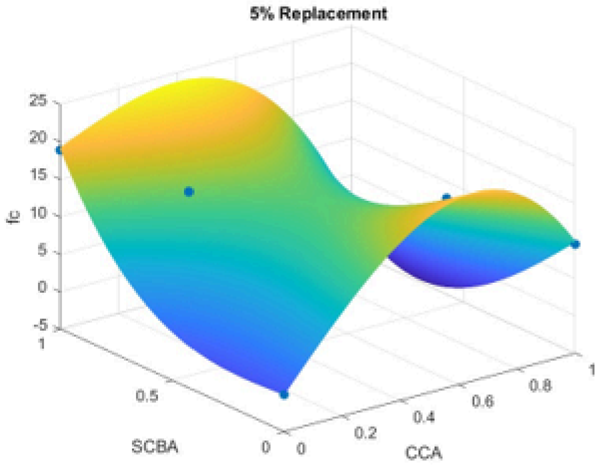


Figure 17

3D Model for 15% Cement Replacement using Response Surface Methodology

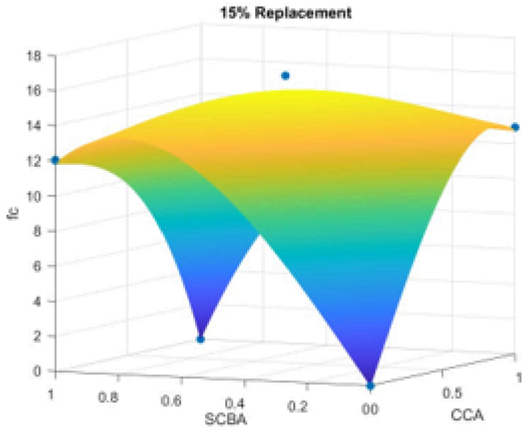
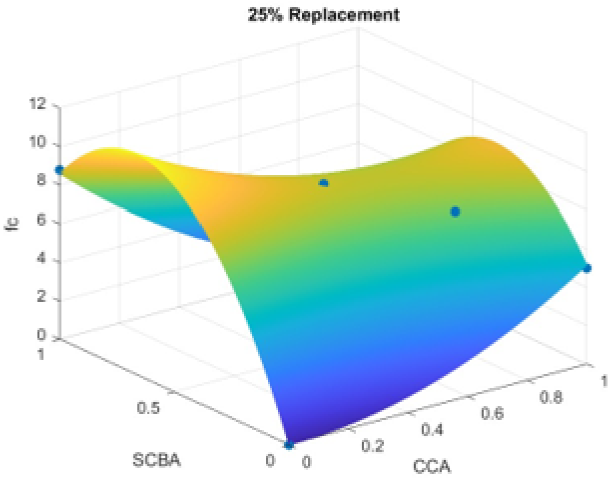


Figure 18

3D Model for 25% Cement Replacement using Response Surface Methodology



Discussion

The findings of this study support the alternative hypothesis that there is a significant difference in the strength of concrete samples based on the percentage content of sugarcane bagasse ash (SCBA) and coconut coir ash (CCA) compared with ordinary Portland cement (OPC) concrete.

A notable improvement in workability was observed with increased ash content, particularly at the 25% replacement level, where slump values were higher. This enhancement is attributed to the porous structure and pozzolanic activity of SCBA and CCA, which improve water retention and mixture flowability.

In terms of compressive strength, mixtures containing 5% and 15% partial replacements demonstrated performance comparable to, or even exceeding, that of the control mix. This suggests that low to moderate replacement levels—especially those with a higher proportion of SCBA—are effective in maintaining structural integrity. However, the noticeable decline in strength at the 25% replacement level highlights a threshold beyond which the reduction in cement content begins to adversely affect performance. This finding aligns with the existing literature, which notes that excessive pozzolanic material may weaken matrix bonding and lead to a dilution effect.

Overall, the results validate the potential of SCBA and CCA as sustainable and eco-friendly alternatives to traditional cement. Their use can significantly reduce cement consumption, lower carbon emissions, and repurpose agricultural waste, contributing to more sustainable construction practices. Nevertheless, further investigation is needed. Future studies should incorporate flexural strength testing, assess a wider range of mix designs, and examine the influence of different aggregates and curing conditions to better evaluate long-term durability and optimize concrete performance.

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