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Influence of Agricultural Waste as a Partial Substitute for Cement in Flowing Concrete for a Sustainable Environment

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ABSTRACT

Large quantities of corn cobs, rice husks, and sugarcane bagasse are often burned or left to decay, contributing to air pollution and greenhouse gas emissions in many rural areas of Indonesia. However, earlier studies indicated that the ashes from these agricultural wastes have the potential to serve as partial substitutes for cement in concrete production, reducing environmental pollution. Because of their rich silica composition, the pozzolanic properties of corn cob ash (CCA), rice husk ash (RHA), and sugarcane bagasse ash (SBA) can improve the long-term performance of concrete. This research investigated the use of rice husk ash, sugarcane bagasse ash, and corn cob ash as alternative materials for partially replacing cement, focusing on their effects on the flowing concrete with the addition of Sika-Viscocrete as a superplasticizer. This study examined the properties of flowing concrete, including unit weight, compressive strength, and the efficiency of cement utilization. The unit weight of concrete was tested following SNI 1973:2008, while its compressive strength was evaluated in accordance with SNI 1974:2011. This study applied statistical analysis and linear regression. Experimental findings showed that the measured unit weight values were consistently within the interval of 2300-2500 kg.m^{-3} and, according to the measured unit weight, the concrete was considered normal-weight concrete. The highest compressive strength obtained was 35.22 MPa at 7% variation of corn cob ash, and the highest efficiency in cement utilization was observed in flowing concrete with corn cob ash substitution. This is because among the alternatives, corn cob ash achieved the greatest strength improvement per unit of cement at 1.13 MPa per kg.m^{-3}. Statistical analysis revealed the effect of substitution levels, and the regression analysis yielded several data-based equations. Employing agricultural waste ash as a partial cement substitute provides a sustainable pathway toward reducing overall cement consumption.

1. INTRODUCTION

In Indonesia, the accumulation of agricultural wastes such as rice husks, sugarcane bagasse, and corn cobs is becoming a significant environmental concern. Indonesia is known as an agricultural country where people mostly work as farmers. Rice milling generates rice husk waste in the form of rice husks, amounting to 20-30% of the total rice production (Budiarti et al. 2023, Faried et al. 2021). Based on information from the Central Statistics Agency in 2025, Indonesia's rice production was approximately 53.14 million tons, so the amount of husk obtained was more than 10 million tons (BPS 2025). According to BPS (2024), sugarcane plantations in Indonesia in 2023 amounted to 489.34 thousand hectares, and they produced 2.23 million tons of sugar. In general, the bagasse produced from one sugar factory was 32% (Legiso et al. 2020), so the sugarcane bagasse produced is around 700,000 tons. In 2024, the corn harvest area was 2.55 million hectares (BPS 2025). From that area, it produced 15.14 million tons of corn kernels, or around 5.94 tons per hectare. This amount is likely to increase every year. As the amount of corn kernels produced increases, so does the amount of corn cob waste. There will normally be an accumulation of waste because the natural process of waste decomposition is slow. This may become an issue if the waste is not handled correctly.

However, earlier studies revealed that the ashes from rice husk, sugarcane, and corn cobs contained silicon dioxide (SiO_2), suggesting that they could be utilized to make concrete or other building materials. A pozzolan is generally described as a material that is either siliceous or a combination of aluminous and siliceous components. On its own, it exhibits little to no cementing ability; however, when moisture is present, and it interacts with calcium hydroxide at normal temperatures, it produces compounds with strong cementitious properties. In concrete production, pozzolans are often utilized as supplementary minerals. Within cementitious systems, their role is particularly significant in promoting the formation of calcium silicate hydrate. Among the various options, agricultural and industrial by-product pozzolans are regarded as the most practical alternatives for advancing sustainable binder development (Albiajawi et al. 2022). From previous research, rice husk ash contains 88% silica (Sudarsan et al. 2023), corn cob ash contains 66.38% silica (Adesanya & Raheem 2010), and sugarcane bagasse ash contains 75% silica (Maglad et al. 2023). This indicates that ashes derived from agricultural residues possess pozzolanic properties. When these materials react with calcium hydroxide, they generate calcium silicate hydrate (C-S-H), a compound that enhances the binding of concrete components and contributes to improved material performance.

In Indonesia, there is a problem in the field of construction materials that contributes to environmental degradation, namely the negative effects of cement production. In 2023, Indonesia was ranked 8th among the world's cement producers (CNBC 2024). This contributes to environmental degradation because the production of cement releases CO_2 into the air, causing the greenhouse effect. According to Ali et al. (2011) and Fayomi et al. (2019), the manufacture of one kilogram of cement is estimated to release about 0.5–0.9 kilograms of CO_2. The rise in CO_2 emissions contributes to various environmental issues, including flooding, global temperature increases, and biodiversity loss (Dziejarski et al. 2023). Cement production contributes 8% of global CO_2 emissions, with annual cement production reaching about 4 billion tons a year (Chatham 2018).

Concrete remains the material that is most often applied in construction due to its adaptability, mechanical strength, and economic advantages. Among various assessment techniques, the compressive strength test is regarded as the most fundamental and widely implemented. This method yields essential insights into how concrete responds to axial compressive loads, which is critical for maintaining structural safety and reliability in both buildings and infrastructure projects (Yankelevsky 2024). In addition, the unit weight of concrete represents a key physical property that indicates the density and compactness of the material, measured in kilograms per cubic meter ($kg.m^{-3}$). This characteristic is central to categorizing concrete into three primary groups: lightweight concrete (generally less than 1900 $kg.m^{-3}$), normal-weight concrete (2200–2500 $kg.m^{-3}$), and heavyweight concrete (greater than 2500 $kg.m^{-3}$) as defined in the Indonesian National Standard (SNI 03-2847-2002). Such classification is significant because each type of concrete is designed to fulfill different structural and functional requirements. For instance, lightweight concrete is typically applied in non-structural elements and for its insulating properties; normal-weight concrete is the standard choice for most structural works, while heavyweight concrete is employed in specialized contexts such as radiation barriers and counterbalancing structures.

According to Trimurtiningrum & Subakti (2016), flowing concrete refers to a mix with exceptionally high workability and a slump value of more than 19 cm (7.5 inches) without segregation and bleeding. Flowing concrete contains coarse aggregates, water, fine aggregates, cement, and chemical admixtures. Flowing concrete can be formed using small sizes of coarse aggregate, a low water-cement ratio, and a superplasticizer. In this study, the superplasticizer material used was ViscoCrete®-3115N. This product can create a high-flow value of concrete; therefore, it can support the formation of concrete with high workability. Flowing concrete can be used to reduce costs due to the minimal compaction process, can speed up construction, and reduce the number of workers, as flowing concrete is relatively easier to compact itself with less assistance from compaction tools than normal concrete.

Considering the above, further efforts need to be made to minimize harmful environmental consequences. Over the last decade, concrete manufacture has led to the development of environmentally friendly concrete (Nomani et al. 2025). According to Verian et al. (2018), environmentally sustainable concrete is mainly produced by partially replacing cement with industrial and agricultural residues, while also utilizing recyclable materials and wastes as aggregate substitutes. In this study, efforts were made to minimize the use of cement by using waste materials in the form of sugarcane bagasse ash (SBA), rice husk ash (RHA), and corn cob ash (CCA) as a partial substitute for cement for the manufacture of flowing concrete materials. This research used flowing concrete test specimens with Sika-Viscocrete as the superplasticizer. This research investigated the use of sugarcane bagasse ash (0%, 2.5%, 5%, 7.5%, and 10%), rice husk ash (0%, 5%, 7.5%, 10%, and 12.5%), and corn cob ash (0%, 4%, 5%, 7%, and 9%) as partial cement replacements in flowing concrete. This study examined the properties of flowing concrete, including unit weight, compressive strength, and the efficiency of cement utilization. The unit weight of concrete was tested following SNI 1973-2008, while its compressive strength was evaluated in accordance with SNI 1974-2011. This study applied statistical analysis and linear regression.

2. MATERIALS AND METHODS

2.1. Materials

This study used the following main materials (Fig. 1):

1. **Coarse Aggregate:** The coarse aggregate employed was crushed stone gravel. Two size gradations were utilized, namely 5–10 mm and 10–20 mm. The mixture proportion consisted of 75% coarse aggregate with a size of 10–20 mm and 25% with a size of 5–10 mm. The percentage combination of these aggregates was determined through a trial-and-error method to obtain an appropriate gradation for the concrete mix.
2. **Fine aggregate**: The fine aggregate employed was natural sand obtained from Lumajang. Based on a proportioning process conducted through trial-and-error analysis, the mix composition was established at 52% fine aggregate and 48% coarse aggregate, ensuring an appropriate balance in particle gradation for the concrete mixture.
3. **Water:** The water utilized was tap water supplied by the local municipal system (PDAM). A visual inspection was conducted to ensure its quality, confirming that the water was clear and free from impurities such as silt, oil, and salts.
4. **Cement:** The type of cement applied was Portland Composite Cement (PCC), which was selected due to its suitability for concrete production and compliance with standard construction requirements.
5. **Superplasticizer:** The superplasticizer employed was ViscoCrete–3115N, incorporated at a dosage of 1.5% by weight of cement.
6. **Cement Substitution:** Cement substitution in this study was carried out using supplementary materials such as sugarcane bagasse ash, rice husk ash, and corn cob ash, all of which were processed to pass through a No. 200 sieve.

2.2. Flow Chart

This research investigated the use of sugarcane bagasse ash (0%, 2.5%, 5%, 7.5%, and 10%), rice husk ash (0%, 5%, 7.5%, 10%, and 12.5%), and corn cob ash (0%, 4%, 5%, 7%, and 9%) as partial cement replacements in flowing concrete. As shown in Fig. 2, this study examined the properties of flowing concrete, including unit weight, compressive strength, cement utilization efficiency, statistical analysis, and linear regression.

The percentage variations employed in this study were determined with consideration of previous research

Fig. 1: Materials used in this study: (a) coarse aggregate; (b) fine aggregate; (c) cement; (d) water; (e) superplasticizer.

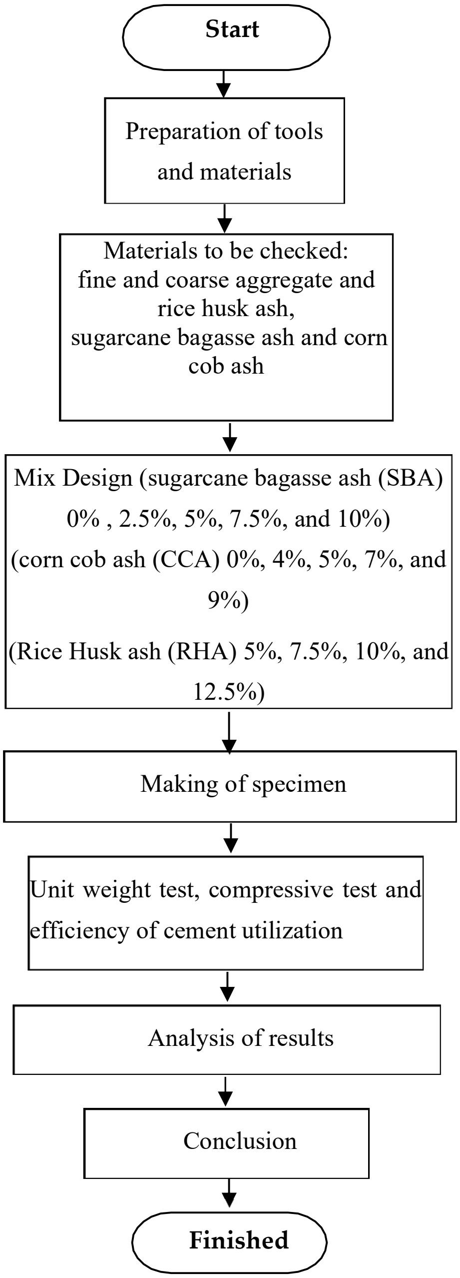


Fig. 2: Flowchart of the research.

findings, and the relevant studies, along with their underlying justifications, are presented below:

Research on the incorporation of sugarcane bagasse ash in cementitious materials has yielded encouraging outcomes. One study employed substitution levels of 0%, 5%, 10%, 15%, 20%, and 25% of the cement weight, demonstrating that partial replacement with sugarcane bagasse ash produced compressive strengths surpassing the design target, with the most substantial enhancement observed at the 5% level (Rompas et al. 2013). Further evidence is provided by Wiyono et al. (2017), who utilized sugarcane bagasse ash in mortar mixtures at 0%, 2%, 4%, 6%, 8%, and 10%. Their findings indicate that the 8% replacement achieved the lowest water absorption and delivered the highest compressive strength among the evaluated mixtures. In view of these prior results, the present study adopts bagasse ash substitution levels of 0%, 2.5%, 5%, 7.5%, and 10%. The selected range reflects concentrations identified in earlier research as yielding optimal mechanical performance, whereas higher replacement levels within the 15%–25% interval have generally been associated with reduced compressive strength.

Suhirkam & Dafrimon (2014) investigated concrete incorporating rice husk ash in combination with a superplasticizer. In their study, a portion of the cement was replaced with rice husk ash at levels of 2.5%, 5%, 7.5%, and 10%, with the highest compressive strength recorded at the 10% substitution. Similarly, Yulianto & Mukti (2015) examined the influence of rice husk ash replacement on the compressive strength of concrete using a mix proportion of 1 part cement, 2 parts sand, and 3 parts coarse aggregate. Their investigation employed substitution levels of 5%, 10%, and 15%, where previous findings identified 5% as the most effective proportion, while a marked reduction in compressive strength occurred at 15%. In consideration of these prior results, the present study adopts rice husk ash substitution levels of 0%, 5%, 7.5%, 10%, and 12.5%, as earlier research consistently indicated that the optimal performance lies within this range.

Hepiyanto & Firdaus (2019) conducted an experimental study employing corn cob ash as an auxiliary material to evaluate its effect on the compressive strength of concrete. Replacement levels of 0%, 4%, 8%, and 12% of the cement mass were assessed, and the findings revealed that all mixtures achieved compressive strengths exceeding the design requirement, with the most favorable result observed at the 4% substitution. Subsequently, research by Handayani (2020) explored the use of corn cob ash as a partial cement replacement at proportions of 0%, 3%, 5%, 7%, and 9%. Their results demonstrated that the 7% mixture produced the highest compressive strength, and the same proportion yielded the optimum flexural strength of beam specimens at the corresponding age. Drawing upon the trends identified in these previous investigations, the present study adopts substitution levels of 0%, 4%, 5%, 7%, and 9% of the cement weight. This range was selected because prior studies consistently indicated that the optimal mechanical performance occurs within these intervals.

Table 1: Proportion of corn cob ash (CCA) in flowing concrete.

Material	CCA (0 %)	CCA (4 %)	CCA (5 %)	CCA (7 %)	CCA (9 %)
Cement ($kg.m^{-3}$)	455.5	449.9	448.5	445.5	442.4
Water ($kg.m^{-3}$)	202.7	202.7	202.7	202.7	202.7
Coarse Aggregate (5-10 mm) ($kg.m^{-3}$)	202.5	200.9	200.6	199.8	198.9
Coarse Aggregate (10-20 mm) ($kg.m^{-3}$)	628.5	623.8	622.5	620.0	617.5
Fine Aggregate ($kg.m^{-3}$)	920.8	913.9	912.01	908.4	904.7
Superplasticizer ($kg.m^{-3}$)	6.83	7.030	7.081	7.185	7.293
Corn Cob Ash ($kg.m^{-3}$)	0	18.75	23.60	33.53	43.76

Table 2: Proportion of sugarcane bagasse ash (SBA) in flowing concrete.

Material	SBA (0 %)	SBA (2.5 %)	SBA (5 %)	SBA (7.5 %)	SBA (10 %)
Cement ($kg.m^{-3}$)	455.5	452.07	448.5	444.7	440.9
Water ($kg.m^{-3}$)	178.2	178.6	178.7	178.8	178.9
Coarse Aggregate (5-10 mm) ($kg.m^{-3}$)	199.1	198.1	197.1	196.1	195.0
Coarse Aggregate (10-20 mm) ($kg.m^{-3}$)	616.6	613.8	610.6	607.4	604.1
Fine Aggregate ($kg.m^{-3}$)	918.4	914.0	909.4	904.6	899.7
Superplasticizer ($kg.m^{-3}$)	6.83	6.95	7.08	7.2	7.35
Sugarcane Bagasse Ash ($kg.m^{-3}$)	0	11.59	23.6	36.1	48.98

Table 3: Proportion of rice husk ash (RHA) in flowing concrete.

Material	RHA (0 %)	RHA (5 %)	RHA (7.5 %)	RHA (10 %)	RHA (12.5 %)
Cement ($kg.m^{-3}$)	455.5	448.5	444.7	440.9	436.8
Water ($kg.m^{-3}$)	186.5	186.7	186.8	186.9	186.9
Coarse Aggregate (5-10 mm) ($kg.m^{-3}$)	194.4	192.5	191.5	190.4	189.3
Coarse Aggregate (10-20 mm) ($kg.m^{-3}$)	598.1	592.1	589.0	585.7	582.4
Fine Aggregate ($kg.m^{-3}$)	890.4	881.6	876.9	872.1	867.1
Superplasticizer ($kg.m^{-3}$)	6.83	7.8	7.21	7.3	7.5
Rice Husk Ash ($kg.m^{-3}$)	0	23.6	36.06	48.9	62.4

2.3. Flowing Concrete Mix Proportion

This study designed the flowing concrete mixture according to the provisions of SNI 03–2834–2000: Procedures for normal concrete mix design and the EFNARC guidelines. The water-to-powder ratio (w/p), which represents the proportion between the amount of water and the powder materials used, was set at 0.45. This ratio was established through laboratory experiments. A series of trial-and-error tests in the laboratory resulted in a proportion of 52% fine aggregate and 48% coarse aggregate. Furthermore, the coarse aggregate fraction was composed of 75% aggregate with a particle size of 10–20 mm and 25% aggregate with a particle size of 5–10 mm. The mix proportions for each variation are presented in Tables 1, 2, and 3.

Flowing concrete was prepared by substituting a portion of the cement with rice husk ash (RHA), with replacement ratios of 0%, 5%, 7.5%, 10%, and 12.5%. A total of 15 cylindrical specimens with dimensions of 15 cm × 30 cm were subjected to compressive strength testing at the curing ages of 7, 21, and 28 days, resulting in 45 specimens. Similarly, flowing concrete containing sugarcane bagasse ash (SBA) as a cement substitute was prepared with replacement ratios of 0%, 2.5%, 5%, 7.5%, and 10%. Another 45 cylindrical specimens of identical dimensions were prepared and later tested for their compressive strength at 7, 21, and 28 days. In addition, flowing concrete was developed using corn cob ash (CCA) as a partial substitute for cement at various replacement levels of 0%, 4%, 5%, 7%, and 9%. For this series, 45 cylindrical specimens measuring 15 cm × 30 cm were also tested at the same curing ages. Thus, the overall total of test specimens prepared in this research was 135. The specimen preparation and testing setup are shown in Fig. 3.

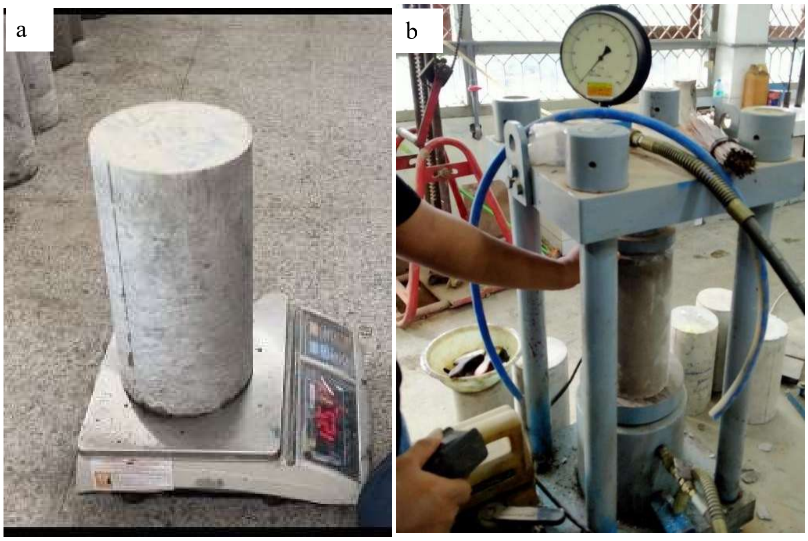


Fig. 3: Testing setup: (a) unit-weight measurement; (b) compressive strength test.

2.4. Testing of Specimens

2.4.1. Unit Weight (Density)

The property of unit weight, often referred to as density, plays an essential role in concrete and is evaluated using the standards specified in SNI 1973:2008. The density measurement is undertaken to verify the actual density of the concrete prior to its application. In this standard, the calculation of unit weight is performed using a specific formula provided in SNI 1973:2008.

$$D = \frac{M_c - M_m}{V_m} \quad ...(1)$$

Where: D = Density ($kg.m^{-3}$)

Mc = Weight of measuring vessel filled with concrete (kg)

Mm = weight of the container (kg)

Vc = the container's volume (m^3)

2.4.2. Compressive Strength Test

Concrete's compressive resistance is the measure of its capacity to resist compressive loads when tested with a compression load testing device. In this method, the specimen is placed in the apparatus and subjected to a steadily increasing load until it fails. The peak load sustained at the point of fracture is taken as the compressive strength value, as specified in SNI 1974:2011. The formula below may be applied to compute the compressive strength of flowing concrete.

$$f'c = \frac{p}{A} \quad ...(2)$$

Where: $f'c$ = Concrete compressive strength (MP_a)

A = the sectional area of the tested sample (nm^2)

P = compressive load (N)

2.5. Statistical Analysis

In this research, the statistical analysis employed an ANOVA (Analysis of Variance). A one-way ANOVA was applied to evaluate the effect of incorporating various proportions of agricultural waste ash as a partial substitution in flowing concrete. The hypotheses were formulated as follows: the null hypothesis (H0) states that the substitution levels exert no significant influence on the characteristic properties of the flowing concrete, whereas the alternative hypothesis (H1) posits that the different substitution percentages produce a measurable effect on these properties. The decision-making procedure relied on comparing the significance value (sig.) generated by the SPSS output with the predetermined significance level (α). The criteria were defined as: (a) when the SPSS significance value exceeds $\alpha = 0.05$, the null hypothesis is accepted; and (b) when the SPSS significance value is below $\alpha = 0.05$, the null hypothesis is rejected.

However, preliminary assumptions required verification before conducting the ANOVA test. One essential prerequisite was the assessment of data normality to ensure that the distribution of the experimental results met the fundamental conditions for valid variance comparison. The dataset must exhibit a normal distribution, as normality testing constitutes a mandatory requirement prior to conducting parametric statistical analysis. When this assumption is not fulfilled, the analysis should be redirected to a non-parametric approach, specifically the Kruskal–Wallis test. The normality criterion

Table 4: Results of the normality test of unit weight.

Group Statistic		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		df	Sig.	Statistic	df	Sig.	
Value	Corn cob ash	0.091	15	0.200*	0.983	15	0.986
	Rice Husk Ash	0.155	15	0.200*	0.931	15	0.286
	sugarcane bagasse ash	0.124	15	0.200*	0.981	15	0.976

Table 5: Results of the ANOVA test of unit weight.

Value					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	112371.054	2	56185.527	136.234	0.000
Within Groups	17321.620	42	412.420		
Total	129692.673	44			

Table 6: Results of the normality test of compressive strength.

Group Statistic		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		df	Sig.	Statistic	df	Sig.	
Value	Corn cob ash	0.189	15	0.158	0.921	15	0.201
	Rice Husk Ash	0.165	15	0.200*	0.959	15	0.673
	sugarcane bagasse ash	0.160	15	0.200*	0.974	15	0.912

Table 7: Results of the ANOVA test of compressive strength.

Value					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	335.702	2	167.851	9.231	0.000
Within Groups	763.679	42	18.183		
Total	1099.382	44			

is determined through the significance value, where a result of Sig. < 0.05 indicates that the data deviate from a normal distribution, while Sig. > 0.05 signifies that the data conform to the assumption of normality.

The results of Table 4 show that a normal distribution is confirmed for the data because the Sig value obtained from the SPSS output is Sig. > 0.05 significance.

The results of Table 5 show that when the significance value is below $\alpha = 0.05$, the null hypothesis is rejected and the alternative hypothesis (H1) is accepted. It means that the different substitution percentages produce a measurable effect on unit weight.

The results of Table 6 show that a normal distribution is confirmed for the data because the significance value obtained from the SPSS output is Sig. > 0.05.

The results of Table 7 show that when the significance value is below $\alpha = 0.05$, the null hypothesis is rejected and the alternative hypothesis (H1) is accepted. It means that the different substitution percentages produce a measurable effect on compressive strength.

3. RESULTS AND DISCUSSION

3.1. Density (Unit-Weight)

The specimens were used to calculate the unit weight of flowing concrete. Fig. 4 shows how the unit weight of flowing concrete is affected by the substitution of the three agricultural waste–based ashes used in this study.

The graph shows that the highest and the lowest unit weight of the flowing concrete are for rice husk ash (RHA) and corn cob ash (CCA), respectively. The unit weight of concrete with rice husk ash substitution shows an increasing trend within the 0–10% range, and it is the same as reported by previous research (Hou 2024), which shows that the reactive SiO_2 and Al_2O_3 present in rice husk ash interact with $Ca(OH)_2$, promoting the formation of hydration products and contributing to void filling in the range of 3–12%. At a substitution level of 2.5% sugarcane bagasse ash, the density shows an increase, which is close to previous research (Althaqafi et al. 2024), which said the substitution of sugarcane bagasse ash into concrete improves the unit weight of concrete through the action of small particles filling

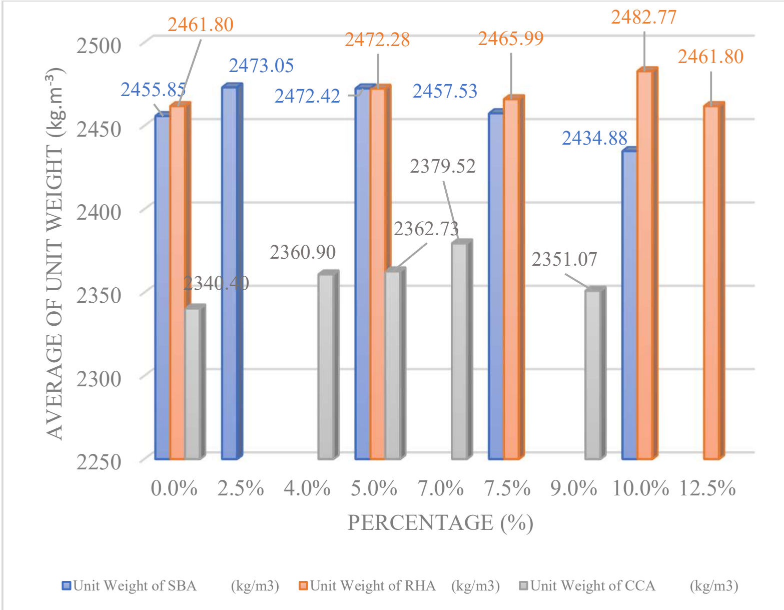


Fig. 4: Influence of rice husk, sugarcane bagasse, and corn cob ashes on the unit weight of flowing concrete.

the pores in the matrix. This densifies the microstructure and can nudge the hardened density upward at very small dosages. A decline in density is observed when sugarcane bagasse ash is substituted at levels beyond 2.5% (i.e., 5–10%), largely because of the comparatively low specific gravity of sugarcane bagasse ash, which is around 1.6–1.9, in contrast to ordinary Portland cement at about 3.15. When cement is partially replaced, the mixture becomes lighter per unit volume, resulting in reduced density in both fresh and hardened states (Memon et al. 2022, Daniel et al. 2024). In addition, the porous and irregular surface characteristics of sugarcane bagasse ash contribute to the formation of internal voids, further decreasing the compactness of the concrete (Althaqafi et al. 2024). While small replacement levels may enhance particle packing through a filler effect, larger proportions generally diminish density as the reduction in cementitious content outweighs any initial densification benefits (Iro et al. 2025). The same behavior is also noted in flowing concrete with the substitution of rice husk ash and with the substitution of corn cob ash. Based on the measured unit weight, the material falls within the range of normal concrete, which typically exhibits a density of about 2200–2500 kg.m^{-3} and is commonly applied in general structural works based on SNI 03-2847-2002.

Based on Fig. 5(a), the highest unit weight of flowing concrete was obtained at a 2.5% sugarcane bagasse ash replacement, reaching 2473.05 kg.m^{-3}, while the lowest value occurred at the 10% replacement level, measuring 2434.88 kg.m^{-3}. Relative to the mix without sugarcane bagasse ash (0%), the unit weight increased at the 2.5%, 5%, and 7.5% substitution levels, with a decrease observed only at 10%. The plotted data follow a linear regression trend described by the equation $y = -229.86x + 2470.2$.

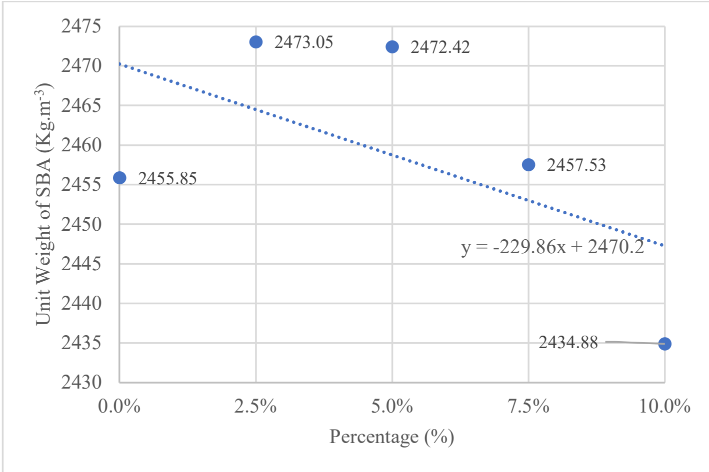
According to Fig. 5(b), flowing concrete achieved its highest unit weight at the 10% rice husk ash replacement level, reaching 2482.7 kg.m^{-3}, while the lowest values were recorded at 0% and 12.5%, both measuring 2461.8 kg.m^{-3}. Compared with the mixture without rice husk ash, the unit weight increased at the 5%, 7.5%, and 10% substitution levels. The trend in the plotted data is represented by the linear regression equation $y = 47.611x + 2465.6$.

Fig. 5(c) shows that the highest unit weight of flowing concrete occurred at the 7% corn cob ash replacement, reaching 2379.5 kg.m^{-3}, while the lowest value was obtained from the control mix (0%), measuring 2340.4 kg.m^{-3}. Compared with the mix without corn cob ash, increases in unit weight were observed at the 4%, 5%, 7%, and 9% substitution levels. The linear regression trend derived from the graph is expressed by the equation $y = 218.3x + 2348$.

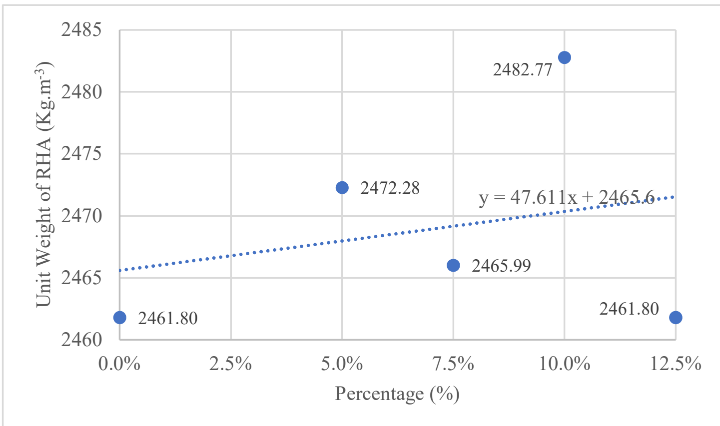
At the same 5% replacement level, the unit weights of flowing concrete were 2472.42 kg.m^{-3} for sugarcane bagasse ash, 2472.28 kg.m^{-3} for rice husk ash, and 2362.7 kg.m^{-3} for corn cob ash. The sequence from the highest to the lowest unit weight is: bagasse ash, rice husk ash, and finally corn cob ash.

3.2. Compressive Strength

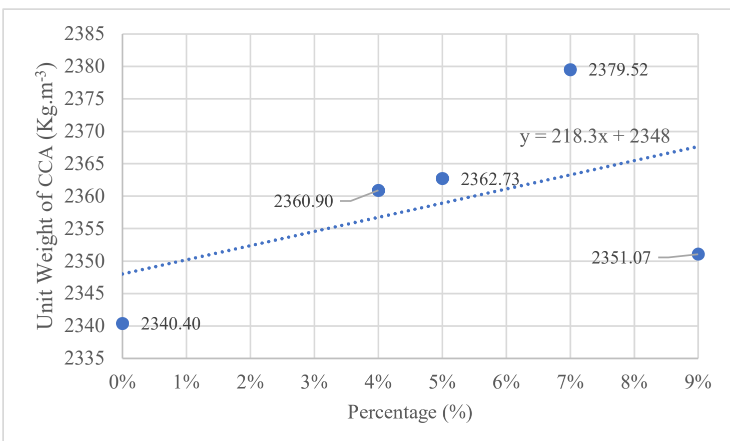
The average value of concrete's compressive strength with



(a)



(b)



(c)

Fig. 5: Linear regression of unit weight at various levels of (a) sugarcane bagasse ash, (b) rice husk ash, and (c) corn cob ash.

the substitution of agricultural waste–based ash is shown in Fig. 6. This figure highlights the effect of these substitutions on the development of compressive strength.

Fig. 6 shows how the substitution of sugarcane bagasse ash (SBA), rice husk ash (RHA), and corn cob ash (CCA) in the flowing concrete affected the compressive strength results. The mixture containing 7% CCA (35.22 MPa) achieves the peak level of compressive strength among all ash substitutions. In the substitution with rice husk ash, the mixture containing 10% RHA achieved the highest compressive strength, which is in agreement with the findings reported by Siddique et al. (2016), who stated that the concrete mix incorporating 10% RHA as a replacement for cement exhibited the highest improvement in compressive strength across all curing ages. Fig. 6 indicates that the substitution of these agricultural waste ashes generally leads to higher compressive strength in comparison with the control mix. This is because sugarcane bagasse ash (SBA), rice husk ash (RHA), and corn cob ash (CCA) contain silica at 75%, 88%, and 66%, respectively. It means that amorphous silica (SiO_2) can act as an alternative material for binding in concrete (Paul et al. 2019). As cement undergoes hydration, the silica in an amorphous state derived from agro-waste ashes reacts with Ca $(OH)_2$, producing additional calcium silicate hydrate (C–S–H). This pozzolanic reaction decreases porosity within the interfacial region of the cement paste and aggregates, thereby enhancing the bond strength and overall compactness of the matrix (Elawadly & Sanad 2025, Memon et al. 2022). The fine particles of sugarcane bagasse ash, corn cob ash, and rice husk ash also fill voids within the microstructure, which further improves adhesion and leads to denser concrete with higher compressive strength (Siddika et al. 2021). On the other hand, when the replacement level of these ashes exceeds the optimum threshold, the excess material tends to increase spacing between aggregates and reduce inter-particle friction. Beyond this limit, the surplus ash mainly behaves as an inert filler rather than reacting with $Ca(OH)_2$, causing a decline in strength (Daniel et al. 2024). Therefore, each ash type demonstrates an optimal substitution percentage at which strength is maximized, after which performance begins to decline.

According to Fig. 7(a), the highest compressive strength of the flowing concrete was recorded at the 2.5% sugarcane bagasse ash replacement, reaching 22.93 MPa, while the lowest value occurred in the control mix (0%), which achieved 20.24 MPa. Compared with the 0% substitution level, the compressive strength increased by 2.5%, 5%, 7.5%, and 10%. The linear regression trend from the plotted data is represented by the equation y = 7.916x + 21.175.

Fig. 7(b) indicates that the highest compressive strength of flowing concrete was achieved at the 10% rice husk ash replacement, reaching 26.53 MPa, while the lowest strength was observed at the 5% level, measuring 22.93 MPa. Relative to the 0% mixture, increases in compressive strength occurred at the 7.5% and 10% substitution levels, whereas decreases were recorded at 5% and 12.5%. The linear regression derived from the graph is expressed as y = 1.8054x + 24.412.

Fig. 7(c) shows that the highest compressive strength of flowing concrete occurred at the 7% corn cob ash replacement, reaching 35.22 MPa, while the lowest value

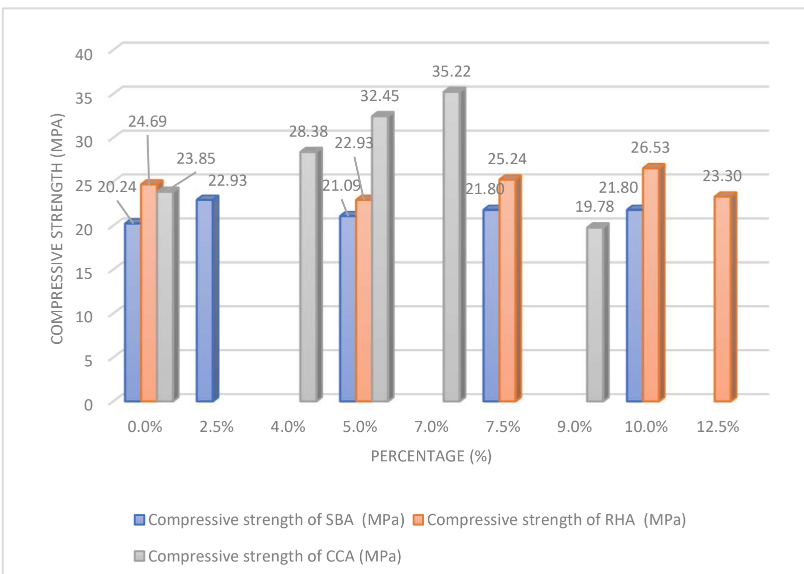
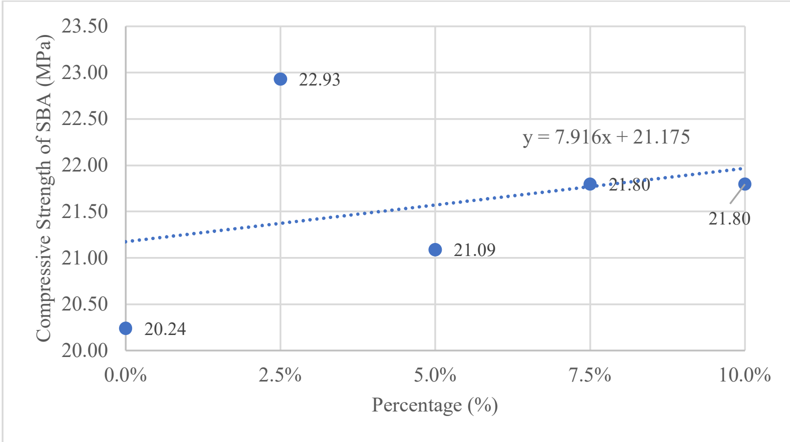
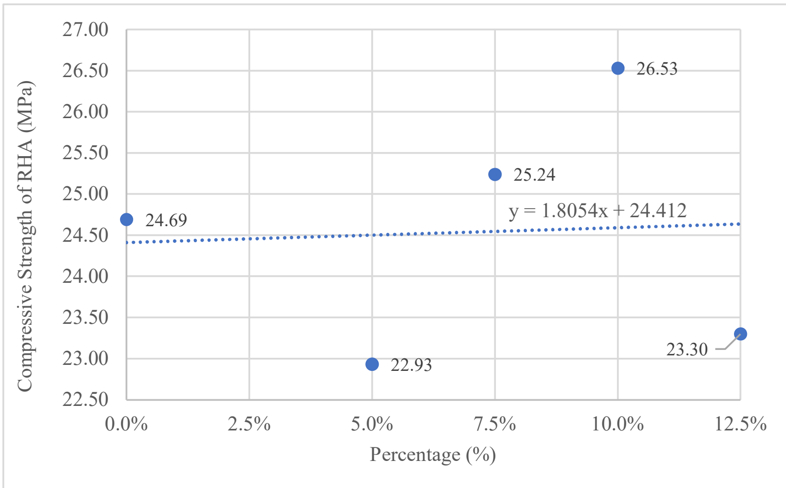


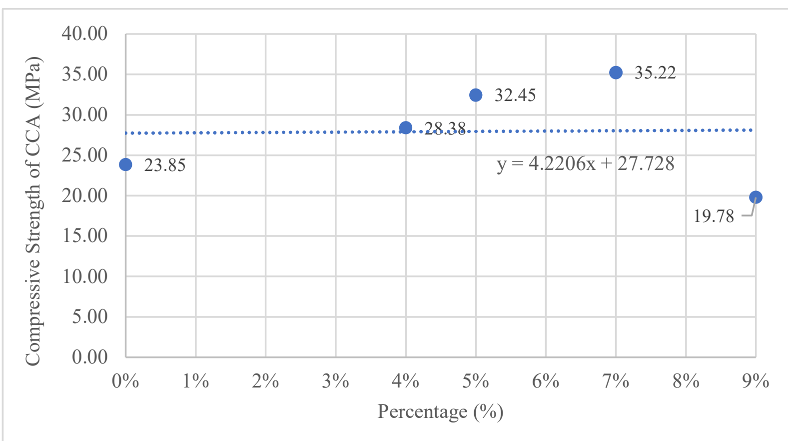
Fig. 6: Influence of rice husk, sugarcane bagasse, and corn cob ashes on the compressive strength of flowing concrete.



(a)



(b)



(c)

Fig. 7: Linear regression of compressive strength at various levels of (a) sugarcane bagasse ash, (b) rice husk ash, and (c) corn cob ash.

was recorded at 9%, measuring 19.78 MPa. Compared with the control mix (0%), increases in compressive strength were observed at the 4%, 5%, and 7% substitution levels, whereas a decrease occurred at 9%. The linear regression equation obtained from the plotted data is y = 4.2206x + 27.728

At the 5% replacement level, the compressive strengths recorded were 21.09 MPa for sugarcane bagasse ash, 22.93 MPa for rice husk ash, and 32.45 MPa for corn cob ash. The ranking from highest to lowest compressive strength is: corn cob ash, rice husk ash, and bagasse ash.

3.3. Efficiency of Cement Utilization

An example calculation used to derive the values presented in Table 8.

- Difference in compressive strength = Compressive strength of the optimal variation

  – Compressive strength of the 0% variation

  = 26.53 MPa – 24.69 MPa

  = 1.84 MPa
- Difference in cement usage = Cement usage at 0% variation – Cement usage at optimal variation

  = 455.55 kg.m^{-3} – 440.86 kg.m^{-3}

  = 14.69 kg.m^{-3}
- The ratio of compressive strength gain

  per unit of cement = Difference in compressive strength: Difference in cement usage

  = 1.84 MPa : 14.69 kg.m^{-3}

  = 0.125 MPa per kg.m^{-3}

The results show a cement reduction of 14.69 kg.m^{-3} with a corresponding compressive strength increase of 1.84 MPa, giving a ratio of 0.125 MPa per kg.m^{-3}

An example calculation used to derive the values presented in Table 9.

- Difference in compressive strength = Compressive strength of the optimal variation

  – Compressive strength of the 0% variation

  = 22.93 MPa – 20.24 MPa

  = 2.69 MPa
- Difference in cement usage = Cement usage at 0% variation – Cement usage at optimal variation

  = 455.55 kg.m^{-3} – 452.078 kg.m^{-3}

  = 3.472 kg.m^{-3}
- The ratio of compressive strength gain

  per unit of cement = Difference in compressive strength: Difference in cement usage

  = 2.69 MPa : 3.472 kg.m^{-3}

  = 0.775 MPa per kg.m^{-3}

The results show a cement reduction of 3.472 kg.m^{-3} with a corresponding compressive strength increase of 2.69 MPa, giving a ratio of 0.775 MPa per kg.m^{-3}.

An example calculation used to derive the values presented in Table 10

- Difference in compressive strength = Compressive strength of the optimal variation

  – Compressive strength of the 0% variation

  = 35.22 MPa – 23.85 MPa

  = 11.37 MPa

Table 8: Cement content and compressive strength of flowing concrete with rice husk ash.

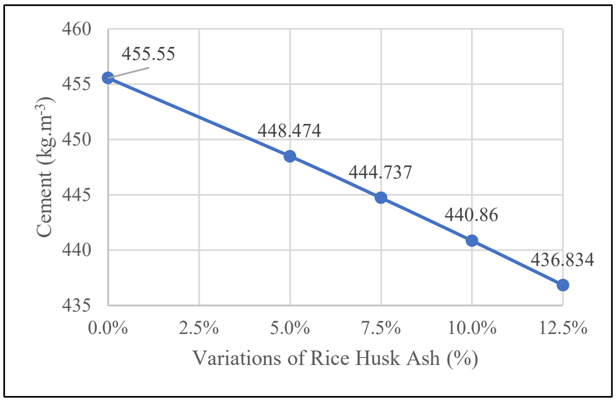
Percentage	Cement (kg.m^{-3})	Compressive Strength (MPa)	Difference in Compressive Strength between Optimal Variation and 0% Variation (MPa)	Cement Usage Difference between Optimal and 0% Variation (kg.m^{-3})
0%	455.55	24.69	1.84	14.69
5%	448.474	22.93		
7.5%	444.737	25.24		
10%	440.86	26.53		
12.5%	436.834	23.3		

Table 9: Cement content and compressive strength of flowing concrete with sugarcane bagasse ash.

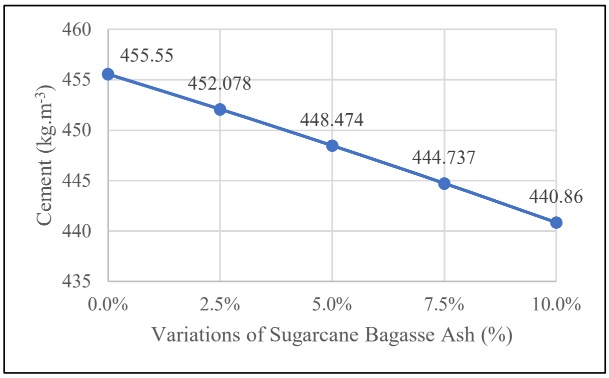
Percentage	Cement (kg.m^{-3})	Compressive Strength (MPa)	Difference in Compressive Strength between Optimal Variation and 0% Variation (MPa)	Cement Usage Difference between Optimal and 0% Variation (kg.m^{-3})
0%	455.55	20.24	2.69	3.472
2.5%	452.078	22.93		
5%	448.474	21.09		
7.5%	444.737	21.8		
10%	440.86	21.8		

Table 10: Cement content and compressive strength of flowing concrete with corn cob ash.

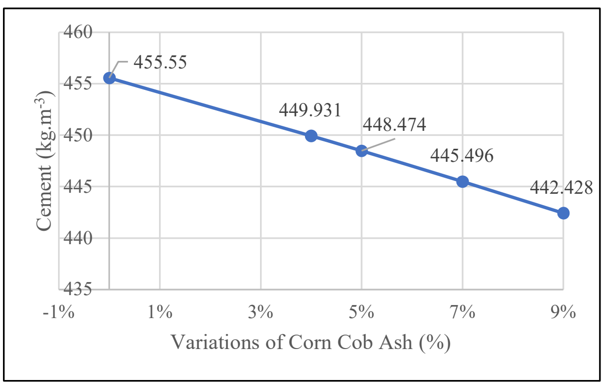
Percentage	Cement	Compressive Strength (MPa)	Difference in Compressive Strength between Optimal Variation and 0% Variation (MPa)	Cement Usage Difference between Optimal and 0% Variation (kg.m^{-3})
0%	455.55	23.85	11.37	10.054
4%	449.931	28.38		
5%	448.474	32.45		
7%	445.496	35.22		
9%	442.428	19.78		



(a)



(b)



(c)

Fig. 8: Cement content at different replacement levels of (a) sugarcane bagasse ash, (b) rice husk ash, and (c) corn cob ash.

- Difference in cement usage = Cement usage at 0% variation – Cement usage at optimal variation

  = 455.55 kg.m^{-3} – 445.496 kg.m^{-3}

  = 10.054 kg.m^{-3}
- The ratio of compressive strength gain

  per unit of cement = Difference in compressive strength: Difference in cement usage

  = 11.37 MPa : 10.054 kg.m^{-3}

  = 1.13 MPa per kg.m^{-3}

The results show a cement reduction of 10.054 kg.m^{-3} with a corresponding compressive strength increase of 11.37 MPa, giving a ratio of 1.13 MPa per kg.m^{-3}.

The most optimal effectiveness of cement use can be seen from the results of the largest value of the ratio of increase in compressive strength per kg.m^{-3} obtained, among others, in rice husk ash the ratio of increase in compressive strength per kg.m^{-3} is 0.125, in bagasse ash the ratio of increase in compressive strength per kg.m^{-3} is 0.775 and in corn cob ash the ratio of increase in compressive strength per kg.m^{-3} is 1.13. Therefore, the optimal effectiveness of cement use is flowing concrete with corn cob ash substitution.

Fig. 8 indicates that increasing the utilization of rice husk ash, bagasse ash, and corn cob ash results in a reduction of cement usage. Employing agricultural waste ashes as partial cement substitutes provides a sustainable pathway toward reducing overall cement consumption.

4. CONCLUSION

The substitution of corn cob ash, rice husk ash, and sugarcane bagasse ash can improve the unit weight of concrete when applied in suitable proportions. Therefore, optimizing the substitution level is essential for achieving sustainable and durable concrete. Based on the measured unit weight, the material falls within the range of normal concrete and is commonly applied in general structural works.

The maximum compressive strength of 35.22 MPa is achieved at a 7% corn cob ash replacement. Moderate use of corn cob ash, rice husk ash, and bagasse ash improves the interfacial transition zone and enhances concrete strength, while excessive substitution reduces performance. Thus, identifying the optimal replacement level is essential for the effective use of these agricultural waste ashes in concrete.

The results show that agro-waste substitution affects cement efficiency in flowing concrete. Corn cob ash provides the greatest strength gain per unit cement (1.13 MPa per kg·m^{-3}), outperforming bagasse ash and rice husk ash. This indicates that corn cob ash offers the most effective enhancement of cement performance and holds strong prospects for use as a supplementary material with sustainable characteristics.

Increasing the use of rice husk ash, bagasse ash, and corn cob ash reduces cement demand, demonstrating that agricultural waste ashes offer a sustainable approach to lowering overall cement consumption.

The statistical evaluation indicates that the various substitution levels yield noticeable differences in unit weight and compressive strength. Meanwhile, the linear regression assessment generated several regression equations derived from the plotted data.

This study shows that agricultural waste ashes can enhance unit weight, compressive strength, and cement efficiency when used at optimal levels, underscoring their potential as sustainable partial cement substitutes. Rice husk ash, bagasse ash, and corn cob ash offer a viable pathway to reducing reliance on Portland cement and lowering environmental impact. Their use is promising for flowable and structural concretes requiring eco-friendly materials. Further research should assess long-term durability, combined ash applications, and feasibility for large-scale implementation.

5. ACKNOWLEDGMENTS

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