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Research Article

Assessment of the strength weight ratio of concrete produced with Sawdust ash from Wood of Gmelina tree as a partial replacement for Cement

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Abstract

This study investigates the potential of Gmelina sawdust ash (GSA) as a sustainable and efficient partial replacement for traditional cement in concrete. With the increasing need for environmentally friendly construction materials, GSA emerges as a promising alternative due to its pozzolanic properties and potential to reduce waste. Concrete samples were prepared using Ordinary Portland Cement (OPC) partially replaced with varying percentages of GSA (0%, 5%, 10%, 15%, 20%, and 25%) in a mix ratio of 1:2:4. Experimental analyses included sieve analysis, slump tests, compressive strength tests, and bulk density assessments were carried out. The chemical composition of GSA was characterized, revealing high silica content conducive for the pozzolanic reaction. Results indicated a progressive decrease in slump and bulk density as GSA content increased, signifying reduced workability and mass. Optimal compressive strength and strength-weight ratio were observed at a specific replacement percentage, suggesting that GSA can enhance concrete performance under controlled conditions. This research provides valuable insights into the application of GSA as a cement alternative, contributing to both waste management solutions and the development of sustainable building practices.

Keyword: Gmelina sawdust ash (GSA), Water, Compressive Strength, Density, Weight

INTRODUCTION

The contemporary landscape of the construction industry is marked by an increasing imperative to adopt sustainable practices without compromising the structural integrity and performance of building materials. In this context, concrete, as a quintessential construction material, finds itself under scrutiny due to the ecological ramifications associated with traditional cement production (Bellis, 2013). As the demand for green and resilient infrastructure rises, the exploration of alternative materials gains prominence, paving the way for innovative solutions that can redefine the environmental footprint of concrete (Caldarone, 2009).

The conventional process of cement manufacturing is notorious for its resource-intensive nature, contributing significantly to carbon emissions and ecological degradation (González and Gutiérrez, 2016). In response to this environmental challenge, researchers and industry professionals are actively seeking sustainable alternatives to traditional cement. Among these alternatives, the repurposing of industrial byproducts has garnered attention, with wood ash emerging as a particularly promising candidate due to its pozzolanic properties (Alabi, and Adediran, 2020). In this context, the Gmelina tree, known for its rapid growth and versatility, presents a compelling avenue for sustainable construction materials (Rashid, 2018).

The Gmelina sawdust ash, a byproduct of wood processing, holds promise not only as a potential cement replacement but also as a means of addressing waste management concerns. Its suitability for incorporation into concrete formulations offers a dual advantage of utilizing a renewable resource and diverting waste from landfills. Consequently, this research aims to delve into the unique properties of Gmelina sawdust ash and assess its viability as a partial replacement for traditional cement in concrete mixes (Sakthivel and Chandrasekar, 2022).

AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to rigorously investigate how the incorporation of Gmelina sawdust ash, as a partial replacement for traditional cement, influences the compressive strength and weight of the resulting concrete. While the objectives are:

a. To characterize the constituent materials used in the production of the concrete produced by incorporating Gmelina sawdust ash, as a partial replacement for cement.

b. To cast cure and crush the concrete produced by incorporating Gmelina sawdust ash, as a partial replacement for cement.

c. To obtain the effect of Gmelina sawdust ash, as a partial replacement for cement on the density of the concrete.

d. To obtain the optimum percentage replacement of Gmelina sawdust ash base on the strength - weight ratio.

MATERIALS AND METHODS

Materials

The materials used in the research work are as follows:

Cement

Ordinary Portland Cement (OPC) is used as a control group for comparison. Dangote 3X cement was used and was gotten from a Cement Depot at Nekede in Imo State and was still at its original production state.

Gmelina Sawdust Ash

Obtained from Gmelina wood processing. It burnt to obtain the ash and should sieved and be finely ground to ensure proper integration into the concrete mix.

Aggregates

Fine aggregates (sand) were obtained from Otamiri River; it is free from impurities and air dried before use. Coarse aggregates (gravel) were gotten from crushed rock at Okigwe, it has a nominal size of 20mm.

Water

Potable water suitable for mixing concrete will be used; the water will be gotten from a tap in concrete laboratory of Civil Engineering in Federal Polytechnic Nekede.

Methods

Tests were performed during this project on concrete and aggregate and they include;

Sieve Analysis

The sieving method adopted was dry sieving and a sample size of about 368g was used for the fine aggregates. This test was carried out to determine the particle size distribution. This test was done in the laboratory using sieve size of different diameter and were staked according to the sieve size, that is, the largest ones on top while the smaller at the bottom. The equipment used in carrying out this test are; sieves of different sizes of different diameter, a scoop which was used to collect the sample, a weighing balance which was used to determine the mass of the aggregate and a brush which was used to remove dirt from the sieve. Sieving was done mechanically using a sieve shaker.

Slump Test

The test was carried out to determine the workability of the concrete. The apparatus used are; a hollow frustrum cone, scooper, sampling tray, shovel, tamping rod, ruler, and funnel (optional). The internal surface of mould was cleaned and superfluous moisture was cleaned before commencing the test. The mould was placed on a horizontal, rigid and non-absorbent surface free from vibration and shock. The mould was held firmly against the surface below and the mould was filled in three layers, each approximately one-third of the height of the mould. Each of the layers was tamped with 25 strokes of the tamping rod, and the strokes were being distributed uniformly over the cross section of the layer. After the third layer has been tamped, the concrete level was strike off with the top of the mould. With the mould still held down, the surface below any concrete which leaked from the lower edge of the mould was cleaned. Then the mould was removed from the concrete by raising it vertically, slowly and carefully. Immediately after the mould was removed, the slump nearest 5mm was measured using meter rule to determine the difference between the highest of the mould and the highest point of the specimen was tested.

Calculation of Mix Proportioning by Weight

This refers to the quantity in terms of mass (kg) of each constituent material in the concrete mix using a cube mould of 15cm.

$\text{Volume of cubic mould, V} = 0.15 * 0.15 * 0.15 = 0.003375m^3$

$\text{Assuming a concrete density of } 2350\text{kg}/m^3$

$\text{Mass of concrete, M} = 2350 * 0.003375 = 7.93125\text{kg}$

$\text{Take mass of concrete} = 8\text{kg}$

Using a concrete mix of 1:2:4, the mass of the constitute material used in the production of the concrete are calculated and presented in Table 1

Table 1: Mass of Materials for 15cm Cube Mould

Mix No	Mix Ratio	Percentage (%) of GSA	Mass of Cement (Kg)	Mass of GSA (Kg)	Mass of Fine Aggregate (Kg)	Mass of Coarse Aggregate (Kg)	Water (kg)
1	1:2:4	0	1.14	0	2.29	4.57	0.57
2	0.95:0.05:2:4	5	1.083	0.057	2.29	4.57	0.57
3	0.9:0.1:2:4	10	1.026	0.114	2.29	4.57	0.57
4	0.85:0.15:2:4	15	0.969	0.171	2.29	4.57	0.57
5	0.8:0.2:2:4	20	0.912	0.228	2.29	4.57	0.57
6	0.75:0.25:2:4	25	0.855	0.285	2.29	4.57	0.57
7	0.7:0.3:2:4	30	0.798	0.342	2.29	4.57	0.57

Compressive Strength Test

The most common and preferred test for strength properties of concrete is compressive strength test. It is carried out using the compressive testing machine. The specimen of concrete (a cube) is placed in the machine and load applied. The point at which deformation or crack occurs on the specimen the testing is stopped at that point and the strength is noted in MPa's. Therefore, this compressive strength test is carried out to determine the strength properties of concrete using the water sachet polyethylene gel as a replacement for cement in the concrete.

RESULTS

The result gotten after the successful completion of the laboratory practical are given below

Sieve Analysis Results

The results of sieve analysis test for river sand and gravel are presented in Table 2 and Table 3. The gradation chart for the river sand and gravel are shown in Figure 1 and Figure 2.

Table 2. Grain Size Distribution of River Sand

Sieve Size (mm)	Soil Retained (g)	% Passing
2.36	85	77
1.18	40	66
0.6	44	54
0.425	42	43
0.3	35	33
0.212	30	25
0.15	32	16
0.075	33	7
Pan	27	0

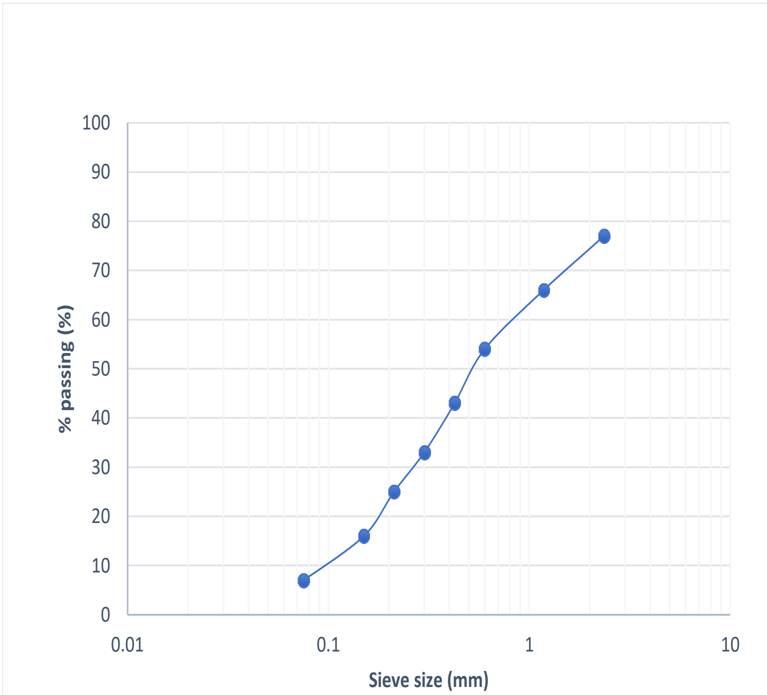

Figure 1. Gradation Curve for River sand

From the Figure 1, the values of D_{10}, D_{30}, and D_{60} for river sand are gotten and computed to get values for Coefficient of uniformity, (C_u) and Coefficient of gradation, (C_c) for river sand.

$D_{10} = 0.10$

$D_{30} = 0.27$

$D_{60} = 0.80$

$$\text{Coefficient of uniformity, Cu} = \frac{D60}{D10} = \frac{0.80}{0.10} = 8$$

$$\text{Coefficient of gradation, Cc} = \frac{(D30)^2}{(D60 \times D10)} = \frac{(0.27)^2}{(0.80 \times 0.10)} = 0.911$$

Table 3. Grain size distribution of Gravel

Sieve Size (mm)	Soil Retained (g)	% Passing
20.0	180	82
16.0	250	57
12.5	300	27
10.0	180	9
4.75	70	2
Pan	20	0

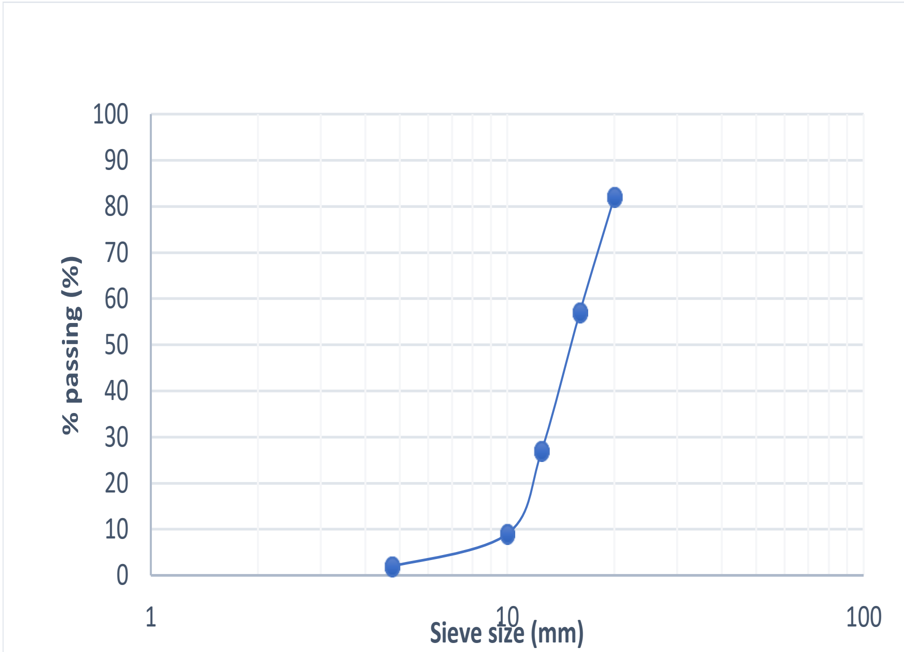

Figure 2. Gradation curve for Gravel

From the Figure 2, the values of D_{10}, D_{30}, and D_{60} for river sand are gotten and computed to get values for Coefficient of uniformity, (C_u) and Coefficient of gradation, (C_c) for river sand.
D_{10} = 11
D_{30} = 14
D_{60} = 17

$$\text{Coefficient of uniformity, Cu } = \frac{D60}{D10} = \frac{17}{11} = 1.55$$

$$\text{Coefficient of gradation, Cc } = \frac{(D30)^2}{(D60 \times D10)} = \frac{(14)^2}{(17 \times 11)} = 1.05$$

Chemical Properties of the Ash test results

The chemical properties of the gmelina leaf ash are presented in Table 4

Table 4. Chemical Property test result of Gmelina Leaf Ash

Parameter	Value (%)
Silica (SiO_2)	52.0
Alumina (Al_2O_3)	20.0
Calcium Oxide (CaO)	10.2
Iron Oxide (Fe_2O_3)	4.8
Magnesium Oxide (MgO)	2.0
Potassium Oxide (K_2O)	2.55
Sodium Oxide (Na_2O)	0.5
Loss on Ignition (LOI)	7.05
pH Level	11.0
Carbon Content	2.0
Zinc (Zn)	0.06
Copper (Cu)	0.04

Slump Test Results

The results of the Slump test of the fresh mixed concrete are presented in Table 5

Table 5. Slump Test Result

Description	Mix ratio W:C:GSA:RS	Slump value (mm)
Control	0.5:1:0:2:4	94
5%	0.5:0.95:0.05:2:4	80
10%	0.5:0.9:0.1:2:4	72
15%	0.5:0.85:0.15:2:4	66
20%	0.5:0.8:0.2:2:4	62
25%	0.5:0.75:0.25:2:4	55

Results of Mass and Bulk Density of Concrete

The results of the mass and bulk density of the concrete at 28days is presented in Table 6. While, the line graph of the average bulk density is shown in Figure 3.

Table 6. Results of Mass and bulk density of Concrete

Mix ratio W:C:GSA:FA:CA	Block No.	Mass (Kg)	Avg. Mass (Kg)	Bulk density (Kg/m^3)	Avg. Bulk density (Kg/m^3)
	$M0_1$	8.06		2388	
0.5:1:0:2:4	$M0_2$	8.06	8.07	2388	2390
	$M0_3$	8.08		2394	
	$M5_1$	8.00		2370	
0.5:0.95:0.05:2:4	$M5_2$	8.01	8.00	2373	2371
	$M5_3$	8.00		2370	
	$M10_1$	7.83		2320	
0.5:0.9:0.1:2:4	$M10_2$	7.83	7.83	2320	2319
	$M10_3$	7.82		2317	
	$M15_1$	7.76		2299	
0.5:0.85:0.15:2:4	$M15_2$	7.77	7.76	2302	2299
	$M15_3$	7.75		2296	
0.5:0.8:0.2:2:4	$M20_1$	7.53		2231	
	$M20_2$	7.56	7.55	2240	2236
	$M20_3$	7.55		2237	
0.5:0.75:0.25:2:4	$M25_1$	7.46		2210	
	$M25_2$	7.46	7.47	2210	2212
	$M25_3$	7.48		2216	

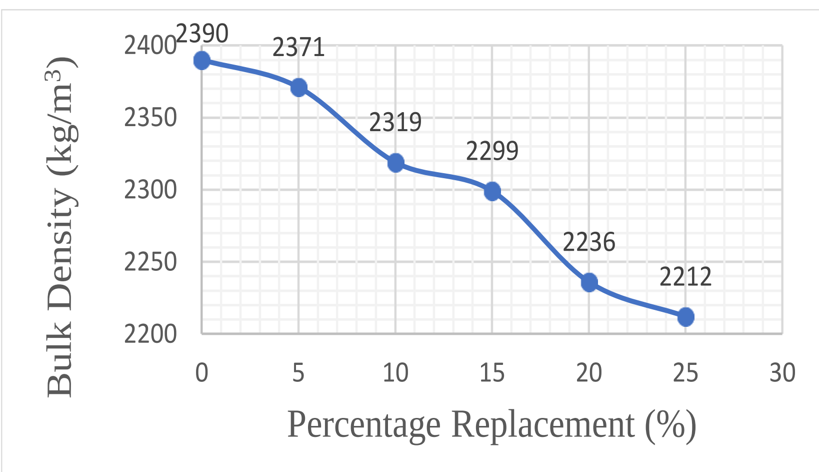

Figure 3. Line chart of the average bulk density

Compressive strength test results

The compressive strength results of the concrete cube are presented in Table 7. While, the line graph of the average compressive strength is shown in Figure 4.

Table 7. 28-day compressive strength test results on the concrete cube

Mix ratio W:C:GSA:FA:CA	Block No.	Failure Load (KN)	Comp. Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)
	$M0_1$	563	25.02	
0.5:1:0:2:4	$M0_2$	565	25.11	25.08
	$M0_3$	565	25.11	
	$M5_1$	560	24.89	
0.5:0.95:0.05:2:4	$M5_2$	562	24.98	24.95
	$M5_3$	563	24.98	
	$M10_1$	528.75	23.5	
0.5:0.9:0.1:2:4	$M10_2$	528.5	23.49	23.49
	$M10_3$	528	23.47	
	$M15_1$	520	23.11	
0.5:0.85:0.15:2:4	$M15_2$	521	23.16	23.13
	$M15_3$	520	23.11	
0.5:0.8:0.2:2:4	$M20_1$	490	21.78	
	$M20_2$	488	21.69	21.68
	$M20_3$	485	21.56	
0.5:0.75:0.25:2:4	$M25_1$	401	17.82	
	$M25_2$	400	17.78	17.87
	$M25_3$	405	18	

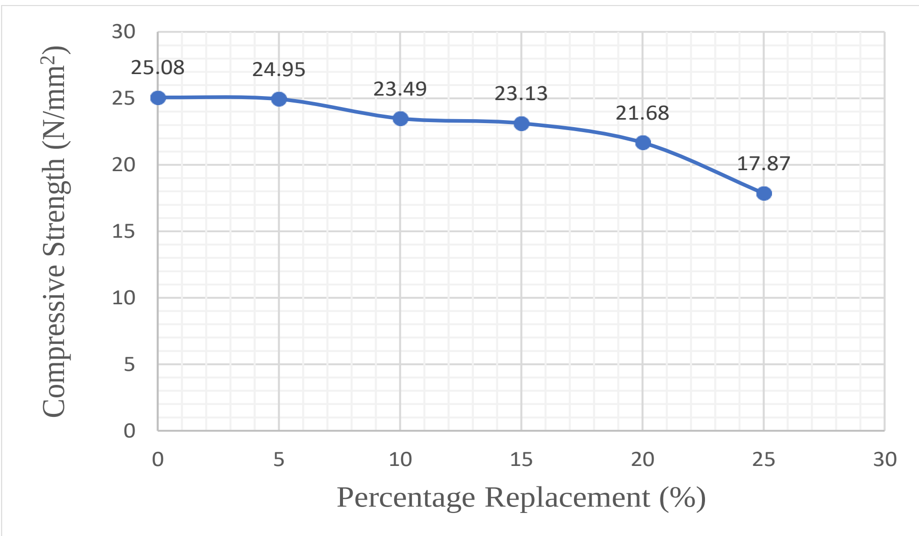

Figure 5. Line chart of the average compressive strengths

Strength-weight ratio results

The compressive strength – weight ratio results of the concrete cube are presented in Table 8. While, the line graph of the average compressive strength – weight ratio is shown in Figure 5.

Table 8. Compressive Strength – Weight Ratio Results

Mix ratio W:C:GSA:FA:CA	Strength- weight ratio (N/m^2Kg)
0.5:1:0:2:4	3107806.7
0.5:0.95:0.05:2:4	3118750
0.5:0.9:0.1:2:4	3000000
0.5:0.85:0.15:2:4	2980670.1
0.5:0.8:0.2:2:4	2871523.2
0.5:0.75:0.25:2:4	2392235.6

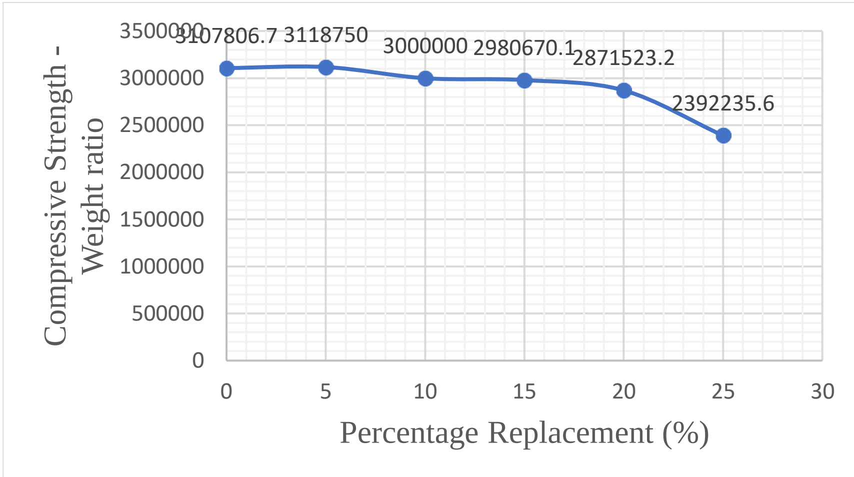

Figure 5. Line chart of the average compressive strength – weight ratio

Analysis of Results

Sieve Analysis Results

Results of sieve analysis show that the coefficient of uniformity (C_u) and coefficient of gradation (C_c) for river sand are calculated as 8 and 0.911 respectively. This result shows that the river sand particles are more uniform in size and lack a well-graded distribution, which may affect the soil's compaction and stability characteristics.

Results of sieve analysis show that the coefficient of uniformity (C_u) and coefficient of gradation (C_c) for the gravel are calculated as 1.55 and 1.05 respectively. This result shows that the gravel soil would be classified as poorly graded gravel (GP) under the Unified Soil Classification System (USCS) due to its low Cu value, indicating a lack of a wide range of particle sizes.

Chemical Properties of the Ash test results

From Table 4, the chemical properties of the ash show similar properties of pozzolans. Hence, it can be used for partial replacement for cement in concrete works.

Slump Test Results

From Table 5, the control mix has a slump value of 94 mm, representing the base workability without any replacement material. This value suggests good workability, allowing for easier handling and compaction in construction. At 5% Replacement: The slump decreases to 80 mm. This drop (by 14 mm from the control) indicates a slight reduction in workability. At 10% Replacement: The slump further decreases to 72 mm, showing a continued trend of lower workability as the replacement material increases. At 15% Replacement: With a slump of 66 mm, workability continues to reduce. At 20% Replacement: At this point, the slump value is 62 mm, indicating further stiffening of the mix. At 25% Replacement: The lowest slump value is observed at 55 mm. This significantly lower slump suggests a much stiffer mix that could be more challenging to work with.

Bulk Density Test Results

From Table 6, Control Mix (0.5:1:0:2:4) having no GSA replacement, has an average mass of 8.07 kg and an average bulk density of 2390 kg/m³. At 5% GSA Replacement, the average mass decreases slightly to 8.00 kg, and the average bulk density is 2371 kg/m³. The reduction from the control mix's bulk density suggests a slight decrease in compactness and weight, as the introduction of GSA, which has a lower density than cement, begins to affect the mix. At 10% GSA Replacement, the average mass is 7.83 kg, and the average bulk density drops further to 2319 kg/m³. At 15% GSA Replacement, the average mass is 7.76 kg, with a bulk density of 2299 kg/m³. At 20% GSA Replacement, the average mass reduces to 7.55 kg, and the bulk density is 2236 kg/m³. At 25% GSA Replacement, the average mass is 7.47 kg, with the lowest bulk density of 2212 kg/m³. This mix represents the lightest block, showing a notable reduction in density as compared to the control mix.

Compressive strength test results

Table 7 presents the results of the compressive strength on the concrete cube. For the Control Mix (0.5:1:0:2:4), Average Compressive Strength: 25.08 N/mm. At 5% GSA Replacement, average Compressive Strength: 24.95 N/mm². With a 5% replacement of cement by GSA, there is a slight decrease in compressive strength (by approximately 0.5%) compared to the control mix. This indicates that a minimal replacement of cement with GSA has a negligible effect on strength. At 10% GSA Replacement, average Compressive Strength: 23.49 N/mm², the compressive strength decreases more noticeably (about 6.3% lower than the control). This shows that increasing GSA content reduces strength but remains within acceptable limits for structural applications, depending on requirements. At 15% GSA Replacement, the compressive strength reduces further to 23.13 N/mm², a decrease of about 7.8% compared to the control. This suggests that while this level of replacement can still be used, it continues to diminish strength incrementally. At 20% GSA Replacement, average Compressive Strength: 21.68 N/mm², there is a significant reduction in compressive strength (by around 13.6% from the control mix). This may still be viable for non-load-bearing applications, though not ideal for higher-strength requirements. At 25% GSA Replacement (0.5:0.75:0.25:2:4), average Compressive Strength: 17.87 N/mm², a reduction of about 28.7% compared to the control. This substantial decrease suggests that such a high level of GSA replacement may not be suitable for structural applications but could be considered for non-structural or light-load applications.

Strength weight ratio results

From Table 8, the Control Mix, Strength-to-Weight Ratio: 3,107,806.7 N/m²Kg. This ratio represents the standard mix without any Groundnut Shell Ash (GSA) replacement. It serves as the benchmark for comparing the effects of GSA replacement in other mixes. At 5% GSA Replacement, strength-to-Weight Ratio: 3,118,750 N/m²Kg, there is a slight increase in the strength-to-weight ratio. This suggests that the inclusion of a small amount of GSA (5%) may marginally enhance the efficiency of load support relative to weight, likely due to slight changes in density and material distribution. At 10% GSA Replacement. strength-to-Weight Ratio: 3,000,000 N/m²Kg, the ratio decreases by about 3.5% compared to the control mix. This indicates that the material becomes somewhat less efficient in terms of strength relative to weight as more cement is replaced by GSA. At 15% GSA Replacement, strength-to-Weight Ratio: 2,980,670.1 N/m²K, the strength-to-weight ratio continues to decline, with a reduction of about 4.1% from the control mix. This shows a continuing trend where increased GSA content gradually reduces material efficiency. At 20% GSA Replacement, strength-to-Weight Ratio: 2,871,523.2 N/m²Kg, the ratio decreases significantly (by about 7.6% compared to the control). This larger drop in strength-to-weight ratio reflects the increasing impact of reduced cement content on overall material performance and structural efficiency. At 25% GSA Replacement, strength-to-Weight Ratio: 2,392,235.6 N/m²Kg, the strength-to-weight ratio falls substantially, with a reduction of approximately 23% compared to the control. This suggests that higher levels of GSA substitution led to considerable losses in efficiency, making the material less effective for load-bearing applications where both strength and low weight are important.

CONCLUSION

The experimental results demonstrate that the partial replacement of cement with sawdust ash from the Gmelina tree significantly affects the physical and mechanical properties of concrete, including bulk density, slump, compressive strength, and strength-to-weight ratio:

a. **Bulk Density**: The incorporation of sawdust ash generally leads to a reduction in the bulk density of the concrete. This decrease can make the concrete lighter, which is beneficial for applications where weight is a concern. However, lower bulk density might also indicate reduced compactness and strength.

b. **Slump**: As the percentage of sawdust ash increases, a corresponding decrease in workability may occur. Higher levels of sawdust ash can lead to a stiffer mix, complicating placement and compaction. Managing the water content in the mix may be essential to maintain adequate workability.

c. **Compressive Strength**: The compressive strength of the concrete decreases as the sawdust ash content increases. A modest replacement (up to 10%) shows a minimal reduction in strength, while higher replacement levels (15% and above) result in significant strength losses. This trend indicates that while sawdust ash can be a sustainable alternative to cement, it is critical to monitor and limit its use to maintain structural integrity.

d. **Strength-to-Weight Ratio**: The strength-to-weight ratio improves slightly with low sawdust ash replacement (around 5%), but declines as the replacement level increases. This suggests that while low percentages can enhance efficiency, higher levels may compromise the material's performance in structural applications.

RECOMMENDATIONS

Based on the conclusions made after this research work, the following recommendations are made:
a. **Optimal Replacement Levels**: For structural applications requiring higher compressive strength, it is advisable to limit sawdust ash replacement to **5-10%**. This range minimizes strength reduction while still incorporating some sustainable material.
b. **Non-Structural Applications**: For non-load-bearing applications, sawdust ash replacement levels of **10-15%** could be acceptable, as long as the potential for reduced strength is considered in the design process.
c. **Adjusting Workability**: To improve workability at higher sawdust ash contents (above 10%), consider adjusting the water content or incorporating superplasticizers. Careful monitoring of the mix's consistency will ensure that adequate workability is maintained without compromising strength.
d. **Further Research**: Additional studies should explore the interactions of sawdust ash with other additives and supplementary materials to enhance both the mechanical properties and workability of the concrete. Investigating the effects of different curing conditions and environmental factors on the performance of sawdust ash concrete could also provide valuable insights.
e. **Quality Control**: Implement strict quality control measures to ensure consistency in mix proportions, particularly when using sawdust ash. Regular testing of concrete samples for compressive strength and workability will help maintain the desired performance characteristics in practical applications.

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