Experimental Study on Physical and Mechanical Characteristics of Concrete with Partial Replacement of Cement by Wood ash and Partial Replacement of Fine Aggregate by Saw Dust Dowder

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Keywords
Wooden ash, Saw dust powder, Compressive Strength, Flexural Strength.

Abstract

Concrete is building material made by mixing cementing material and mineral aggregate with sufficient water to cause cement to set and bind entire mass. Now a days, due to demand of concrete increasing in construction work, it is necessary to develop such sources or material which can replace cement and sand in concrete. However, the cost of cement is rising due to high expenses of production and transportation. Finding alternative construction methods and material to reduce consumption of cement and sand could help reduce the concrete ingredients and their cost.

This experimental study aims to investigate optimum replacement percentage and physical as well as mechanical properties of concrete obtained by patrial replacement of cement by wood ash and partial replacement of fine aggregate by saw dust powder. This process could potentially lead to development of sustainable alternatives to conventional concrete materials by utilizing industrial and agricultural by-products, thereby promoting light weight and eco-friendly construction practices.

In this research, a total of thirty-six concrete cubes of sizes 15 cm×15cm×15cm and thirty-six number of rectangular concrete beams of sizes 10cm×10cm ×50 cm was tested to evaluate physical and mechanical properties including compressive strength, flexural strength, water absorption, workability of concrete and specific gravity, sieve analysis (gradation) and fineness test of concrete ingredients. The physical and mechanical properties of these mixes were compared with conventional concrete to assess performance.

For the test, specimens were divided into four test schemes, (0%, 2.5%, 5% and 7.5%) replacements of cement by wooden ash and fine aggregate by saw dust powder respectively. Each scheme consisted of three specimens (for 7 days, 14 days and 28 days strength by average of 3 samples of each tests scheme). There were additional three concrete cubes for water absorption test and four slump cone samples for workability test were cast.

The study concludes that compressive strength decreased with the addition of wood ash and sawdust powder from the beginning, while the flexure strength started to decrease beyond 5% replacement of wood ash and sawdust powder, which have properties of lower binding capacity and increase concrete porosity. So partial replacements of cement and fine aggregate by wood ash and saw dust powder respectively up to 5% can be effectively used in concrete, contributing to waste utilization, reduced environmental impact, and cost optimization.

Received: 4 October 2025
Revised: 28 November 2025
Accepted: 5 December 2025

ISSN: 3059 - 9687

Chapter 1: Introduction
Background
Concrete is a commonly used building material in the world. Conventional concrete is a blend of cement, fine aggregate, coarse aggregate, and water[1]. The demand for concrete is increasing at a higher rate due to development in infrastructure and construction activities all around the world. Nowadays, due to huge demand of concrete in construction work, it is necessary to develop or find such sources or material which can replace cement and sand in concrete is essential. Contribution of the cement industry to the global emission of greenhouse gases, especially CO2 , in the built environment, is over 7% [2].

Saw Dust

Saw dust is a byproduct of mechanical processing or milling wood (timber) into different sizes and shapes. Wood sawdust, wood chippings, or wood shavings could be utilized to create lightweight concrete. It is composed of fine particles of wood. It is a by-product cutting lumber with a saw. Generation of wood wastes in sawmill is an unavoidable environmental pollution and hence a great efforts are made in the utilization of such waste[3].Concrete including sawdust possessed unique characteristics and presented better outcomes for the thermal and mechanical characteristics of the cement based composite, making it economical compared to various other materials in the construction sector[4]. The use of good quality saw dust powder as a partial replacement for fine aggregate (sand) reduces demand for sand, makes concrete lightweight, improves insulation. In addition, the use of sawdust as a partial replacement of sand have great importance in the manufacture of light-weight masonry units[5]. Sawmills generate much sawdust, and getting rid of it is typically a hassle. As a result, mountains of sawdust accumulate in landfills around sawmill enterprises[6].

Wood Ash

Wood ash is a by-product of coal-fired power plants and it is a pozzolanic material[7]. Wood ash emerges as a promising candidate, reducing reliance on cement and lowering the carbon footprint of concrete. Wood ash, possessing pozzolanic action, reacts with calcium hydroxide from cement hydration to create extra cementitious compounds and potentially improve concrete properties. The ash particles serve as the filler ingredient, filling the voids in the concrete matrix and improving their overall density and cohesion. This increases the beams shear capability[8]. Thus, scientific studies confirm that the beneficial use of wood ash in concrete to replace Portland cement showed the greatest potential environmental benefits[9]. The use of wood ash also improves the cohesiveness and reduces segregation of concrete.

On an average burning of wood produces 6–10% of ash by the weight of wood burnt and its composition can be highly variable depending on geographical location and industrial processes[10]. The usage of wood ash as replace cement for cement in blended cement is beneficial for the environmental point of view as well as producing low cost construction entity thus leading to a sustainable relationship[11]. It was discovered that wood ash can increase concrete beams bending strength and ductility, especially at early ages. This improvement is attributable to the ash’s pozzolanic reaction, which enhances the bond between the cement matrix and the reinforcing steel. Regarding shear behavior, wood ash can also enhance the reinforced concrete beams shear strength[12]. Sawdust decreases weight and enhances the thermal insulation of concrete; however, it also compromises its strength[13]. The increase in the popularity of using environmental friendly, lightweight construction materials in building industry has brought about the need to investigate how this can be achieved by benefiting environment as well as maintaining the material requirements affirmed in the standards[14].

Chapter 2: Literature Review

V. Ramudu, D. Karthik, et al. (2022-2023) published a research paper on **partial replacement of fine aggregate with saw dust in concrete** investigation of the effect of replacement of fine aggregate by sawdust on the workability, density, and compressive strength of concrete by different percentages. For the investigation, they used concrete cubes with varying sawdust replacement percentages (0%, 10%, 15%, 20%) and tested for compressive strength at 7 and 28 days respectively. Based on the test results, they concluded that optimal replacement percentage was around 10% for maintaining structural integrity and strength decreased as the percentage replacement increases exceeded by 10%.

O. E. Osanyinlokun, C. A. Fapohunda, et al. (31 March 2024) Carried out an **experimental study on compressive, bending and shear properties of reinforced concrete beams containing sawdust ash as partial replacement of cement** to examines the effect of sawdust ash (SDA) as a partial replacement for cement on the compressive, bending, and shear properties of reinforced concrete beams. The experimental study involved mix design, concrete specimen preparation, and mechanical testing (compressive, bending, and shear tests) using a four-point loading system). For the investigation they were prepared the test samples of 120 RC beam specimens (150x150x600 mm for bending test, 150x150x450 mm for shear test) and 105 concrete cube specimens (150x150x150 mm for compressive strength test). Based on the result they concluded that density of saw dust ash concrete falls within the normal weight range and compressive, bending and shear strength of reinforced concrete beam was improved upto 5% replacement of cement by saw dust ash.

Chikwendu S. Ettu, Christian N. Igbo, et al. (2018) publishes a research paper on **Mechanical Properties of Concrete with Partial Replacement of Fine Aggregate by Sawdust** to investigates compressive strength, flexural strength, density and percentage replacement of sand with sawdust. For the investigation concrete cube mould (150×150×150 mm), concrete beam mould (100×100×500 mm), compression testing machine were used and concrete specimens made with sawdust replacing sand at 5%, 10%, 15%, 20%, and 25% by volume, 3 specimens per mix for each test (compressive and flexural) were casted. Based on the study they concluded that density, compressive and flexural strength decreased with higher sawdust. Maximum compressive and flexural strength observed at 5% sawdust. Sawdust can be used as partial fine aggregate replacement in concrete (up to 10%) for non-load bearing structures, contributing to sustainability and cost reduction.

Ashish S. Chawda, Avinash L. Baraskar, et al. (March 2, 2023 publishes a research paper on **experimental investigation on concrete by partial replacement of cement with wood ash and fine aggregate with foundry sand** to investigates the relationships between percentage of wood ash and foundry sand vs compressive strength and workability of concrete. For the investigation compression testing machine, slump cone for workability, standard IS procedure-based testing equipment were used where total 27 number of cubes (150 mm × 150 mm × 150 mm) for compressive strength tests at 7 and 28 days were casted and tested. Based on the study they concluded that maximum compressive strength achieved with 10% wood ash and 20% foundry sand at 28 days. Foundry sand improves workability slightly compared to wood ash alone and higher replacements reduced strength and workability of concrete.

Chapter 3: Materials And Methodology

3.1 Raw Materials

In this section, all the properties of materials were tested such as Compressive strength of concrete, Flexural strength of concrete, Workability test, Water absorption test, Physical properties of aggregate, Sieve analysis of coarse aggregate, Specific gravity of coarse aggregate, Silt content of fine aggregate, Gradation of fine aggregate and saw dust powder, specific gravity of fine aggregate, fineness tests of cement and wooden ash were conducted.

3.2 Compressive Strength of Concrete

Test Specimens:

Size of cube: - 150 mm × 150 mm × 150 mm

Testing Age: - 7 days, 14 days and 28 days.

Empirical formula from Mix Design

The mix design of concrete was done as per IS 10262: 2019[15].

Target Mean Strength $\mathbf{f_{ck,target} = f_{ck}+k\times s}$

Compressive Strength (MPa)=$\frac{\text{Maximum Load (N)}}{\text{Cross−sectional Area (mm2)}}$

3.3 Flexural Strength of Concrete

Empirical formula from mixed design

$f_{cr}=0.7 \text{ x } \sqrt{f_{ck}}$

For crack at middle third (two-point loading):

Flexural Strength (f_{cr}) = $= \frac{P\ X\ L}{b\ X\ d^2}$

For crack outside middle third:

Flexural Strength (f_{cr}) = $\frac{3\ X\ P\ X\ a}{b\ X\ d^2}$

3.4 Water Absorption Test:

The water absorption test for concrete is an important measure of the rate and amount of water absorbed into a concrete specimen. Water absorption test was conducted with great attention because Water induced corrosion is the major problems for concrete durability.

The water absorption test was carried out as per British Standard 1881-part 122, 2011[16]. Three oven dried specimen of concrete cubes of size (150 mm x 150 mm x 150 mm) were placed for 24 hours in water bath. The initial weight and final weight were recorded, and the percentage of water absorption was determined as per guidelines of the codes. Water Absorption is calculated as below:

Water absorption (%) =$[\frac{W_2-W_1}{W_1}]$x 100

Where, W_1= Oven dried weight of cube sample

W_2 = Saturated weight of cube Sample after water bath

3.5 Workability Test:

Workability of concrete is said to be ease with which freshly mixed concrete can be mixed, placed, compacted, and finished without segregation or bleeding. It shows that how easily concrete can be handled at the construction site still maintaining uniformity and desired strength. It depends upon water-cement ratio, aggregate shape & size, grading of aggregate, usage of admixtures, and casting temperature. For this, slump test was done for every replacement percentage as well as for ordinary concrete.

Chapter 4: Result And Discussion

4.1 Mix Proportion

Mix Proportion of raw material was calculated by design mix of concrete. The grade and mix ratios of concrete mix were found to be M_{25} and 1:1.27:3 respectively. The quantity of concrete ingredients and alternative materials were shown in figure 9. Batching and mixing concrete ingredients were done weight and machine respectively.

4.2 Raw Materials:

In this section, all the properties of materials were tested such as Compressive strength of concrete, Flexural strength of concrete, Workability test, Water absorption test, Physical properties of aggregate, Sieve analysis of coarse aggregate, Specific gravity of coarse aggregate, Silt content of fine aggregate, Gradation of fine aggregate and saw dust powder, specific gravity of fine aggregate, fineness tests of cement and wooden ash were conducted.

Table 1: Mix Proportion

Parameter	Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Ash	Dust	Water (ltr.)
Ordinary Concrete	21.28	27.03	63.85	0	0	9.576
2.5% Ash+Dust	20.748	26.325	63.85	0.532	0.675	9.3367
5% Ash+Dust	20.216	25.65	63.85	1.064	1.35	9.0972
7.5% Ash+Dust	19.684	24.975	63.85	1.596	2.025	8.8578

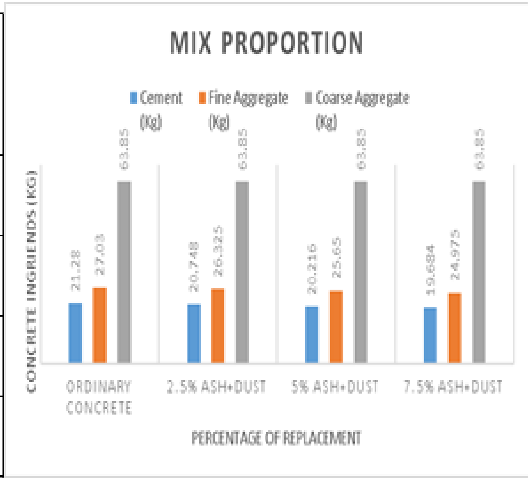


Table 2: Physical Properties of Aggregate

Physical properties	Fine aggregate	Coarse Aggregate 20mm down
Water absorption	1.1	0.72
Specific gravity	2.6	2.7

Table *3*: Specific gravity of coarse aggregate

Weight of flask (W1)	Weight of flask+ aggregate (W2)	Weight of flask+ aggregate + water (W3)	Weight of flask+water (W4)	w2-w1	w3-w4	Specific gravity (W2-W2) / [(W2-W1)-(W3-W4)]
947	1693	2893	2423	746	470	2.7

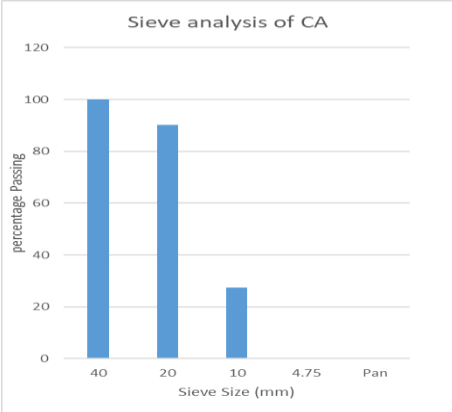
4.3 Properties of coarse aggregate

For this, sieve analysis was conducted before the specimen prepared (batching work). From laboratory tests, it was shown that 90.34% coarse aggregate used for concrete preparation was finer than required size (20 mm). The coarse aggregate used was obtained from crushing.

The specific gravity of coarse aggregate was found to be 2.7. The result obtained after sieve analysis of coarse aggregate can be shown as figure below.

Table 3 Sieve Analysis of coarse aggregate

Sieve Size (mm)	Aggregate retained on each sieve (gm)	Cumulative weight retained (gm)	Cumulative % retained	% Passing
40	0	0	0.00	100
20	1002	1002	9.66	90.34
10	6520	7522	72.55	27.45
4.75	2814	10336	99.69	0.31
Pan	32	10368	100.00	0.00
Total	**10368**			



4.4 Properties of fine aggregate and saw dust powder

For this, sieve analysis was conducted before the specimen prepared (batching work). From laboratory test, it was shown that 96.72% of fine aggregate used for concrete preparation were finer than required size (4.75 mm) and 99.18% saw dust powder used for concrete preparation were finer than required size (4.75 mm). The fine aggregate used was obtained from crushing whereas the saw dust powder was obtained from local wooden sawmill.

The specific gravity of fine aggregate was found to be 2.6 and average silt content in fine aggregate was obtained 2.77%. The result obtained after gradation of fine aggregate and saw dust powder can be shown as figure below.

Table 4: Silt content test on Fine aggregate

Weight of sample	Weight of sand 200 no. sieve Passing A	Percentage of silt clay content B	Percentage of Silt content = (A-B)/A*100%	Average silt content
500	486.5	13.5	2.77	2.77%

Table 5: Specific gravity of fine aggregate

Weight of flask (W1)	Weight of flask+ aggregate (W2)	Weight of flask+ aggregate + water (W3)	Weight of flask+water (W4)	w2-w1	w3-w4	Specific gravity (W2-W2) / [(W2-W1)-(W3-W4)]
947	1693	2882	2423	746	459	2.6

Table 6: Gradation of Fine aggregate

Sieve Size (mm)	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative Retained (%)	% Passing
10	0	0	0.00	100.00
4.75	28	28	3.28	96.72
2.36	72	100	11.71	88.29
1.180	156	256	29.98	70.02
0.600	162	418	48.95	51.05
0.300	202	620	72.60	27.40
0.150	186	806	94.38	5.62
Pan	48	854	100.00	0.00
Total	854			

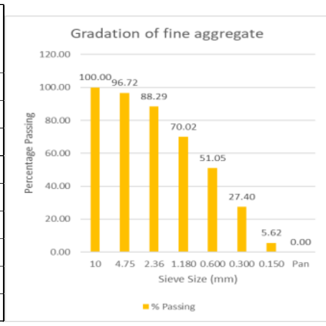
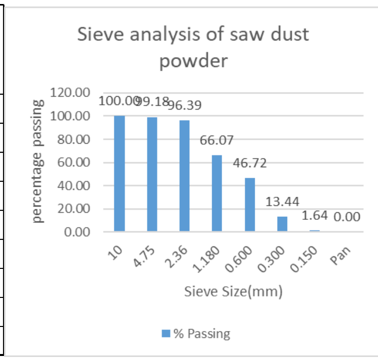


Table 7: Gradation of Saw Dust Powder

Sieve Size (mm)	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative Retained (%)	% Passing
10	0	0	0.00	100.00
4.75	5	5	0.82	99.18
2.36	17	22	3.61	96.39
1.180	185	207	33.93	66.07
0.600	118	325	53.28	46.72
0.300	203	528	86.56	13.44
0.150	72	600	98.36	1.64
Pan	10	610	100.00	0.00
Total	**610**			



4.5 Properties of cement and wooden ash

Fineness test of cement and wooden ash was conducted before the specimen prepared (batching work). From laboratory tests, it was shown that average fineness of cement and wooden ash were found to be 99.1% and 92.8% respectively. The cement used to prepare sample concrete be OPC and wooden ash was collected from local sawmills after burning. The result obtained after tests of cement and wooden ash can be shown below.

Table 8: Fineness Test of Cement

SN	Weight of cement (gm)	Weight of cement 90 µm sieve passing	Weight of cement 90 µm sieve retaining	Passing % of cement	Average fineness of cement %
1	200	198.2	1.80	99.10	**99.10**

Table 9: Fineness Test of wooden Ash

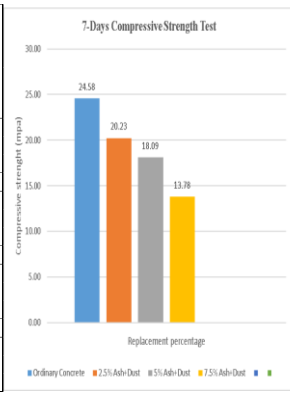
SN	Weight of Ash (gm)	Weight of Ash 90 µm Sieve passing	Weight of Ash 90 µm sieve retaining	% Passing	Average fineness ash %
1	200	192.8	7.20	92.80	**92.80**

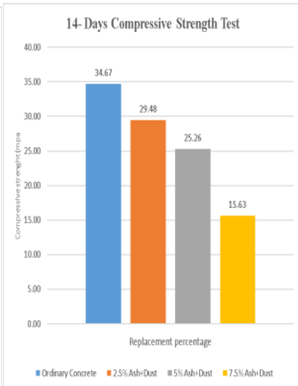
4.6 Fresh properties of concrete

4.6.1 Compressive strength test

The compressive strengths of concrete specimens were determined after 7 days, 14 days and 28 days of curing. The compressive strengths test was conducted on 150 mm x 150 mm x 150 mm cubes. Results of compressive strength of concrete with different percentage levels of wooden ash and saw dust powder have been shown below.

Test Sample	7 days Test Test Date: 8th July, 2025	14 days Test 15th July, 2025	28 days Test 29th July, 2025	Average 7 days Strength MPa	Average 14days Strength MPa	Average 28 days Strength MPa	Remarks
Test Parameter	Stress KN/mm2	Stress KN/mm2	Stress KN/mm2				
Ordinary Concrete M25	25.26	34.67	36.74	**24.58**	**34.67**	**38.06**	
	26.02	36	38.72				
	22.45	33.33	38.71				
2.5% (Ash+Dust)	21.42	28.89	34.29	**20.23**	**29.48**	**33.08**	
	19.69	30.67	31.98				
	19.57	28.89	32.96				
5% (Ash+Dust)	17.17	25.78	27.18	**18.09**	**25.26**	**26.93**	
	18.57	24.44	26.04				
	18.53	25.56	27.56				
7.5% (Ash+Dust)	14.77	15.56	17.62	**13.78**	**15.63**	**18.31**	
	12.7	15.11	18.98				
	13.87	16.22	18.33				





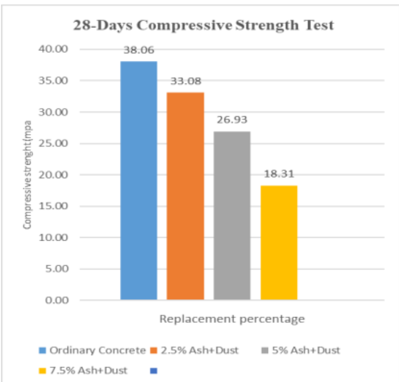
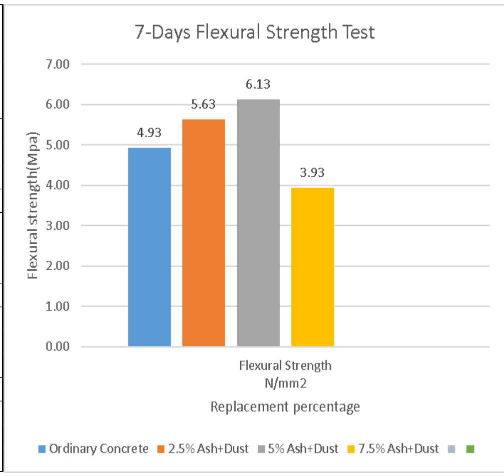


Figure: 7, 14 and 28- Days Compressive Strength (N/mm^2) of Test Sample Respectively.

4.6.2 Flexural strength test:

The flexural strength test of a beam, also known as the modulus of rupture test, was conducted to determine the bending strength of concrete. In this test, a standard concrete beam specimen typically of size 100 mm × 100 mm × 500 mm was placed on two supporting rollers with a specific span (usually 400 mm) and loaded at one-third points or at the center, depending on the method (third-point loading or center-point loading). The load was applied gradually through a hydraulic loading machine until the beam fails. The maximum load at failure was recorded, and the flexural strength was calculated using the appropriate formula based on the loading configuration.

est Sample Da Test Parameter	Average 7 days Strength MPa	Average 14 days Strength MPa	Average 28 days Strength MPa	Remarks
Ordinary Concrete M25	4.93	5.82	6.17	
2.5% (Ash+Dust)	5.63	6.17	6.77	
5% (Ash+Dust)	6.13	6.42	7.20	
7.5% (Ash+Dust)	3.93	5.18	5.95	



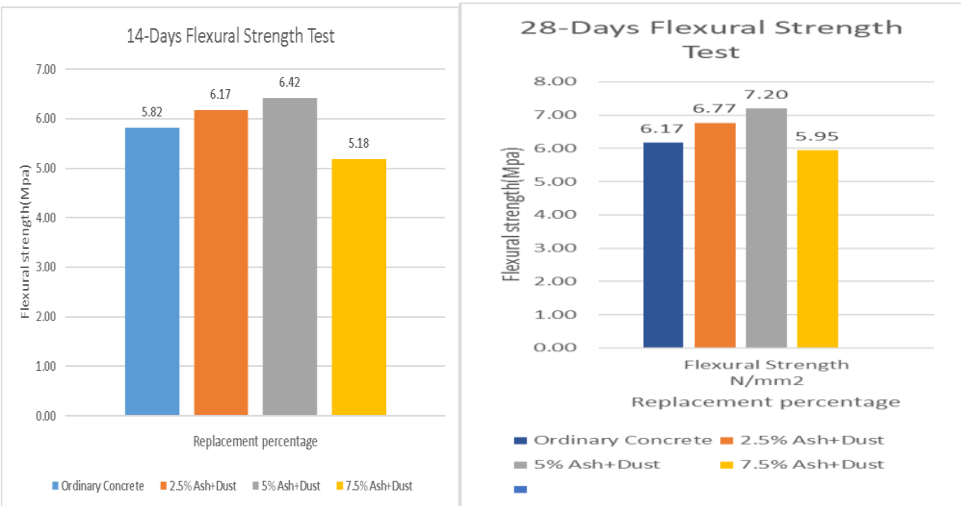


Figure 1: 7, 14 and 28-Days flexural strength (N/mm^2) of test sample respectively.

4.6.3 Water absorption test

Water absorption test refers to amount of water a hardened concrete specimen can absorb when it is exposed to water under control conditions. This test was determined after 28 days of casting. It was shown that percentage of water absorption was increases as percentage of replacement increased, which can be illustrated by figure below.

S.No.	Parameter Content in Mix	Oven Dried weight of Sample (gm) W1	Saturated Weight of Sample after water bath (gm) W2	Water absorption (%) =[(W2-W1)/W1]x 100
1	Ordinary Concrete	8012	8142	**1.62**
2	2.5% (Ash+Dust)	7780	8004	**2.88**
3	5% (Ash+Dust)	7490	7730	**3.2**
4	7.5% (Ash+Dust)	7230	7534	**4.2**

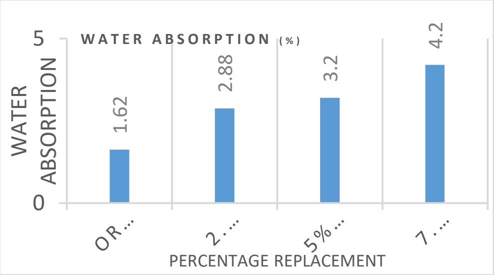


Figure 2: Water Absorption test of concrete

4.6.4 Workability test of concrete

Figure 16 shows the results of the slump tests carried out on concrete produced with different percentage of replacements (0%, 2.5%, 5% and 7.5%) of cement and fine aggregate by wooden ash and saw powder respectively. The slump got ranges from Workability test of concrete was conducted by slump test. From laboratory test, workability of concrete was decreased when replacement percentage of cement and fine aggregate by wooden ash and saw dust powder was increased. The result obtained after slump test of the concrete and wooden ash can be shown as figure below.

S.No.	Replacement Percentage (Ash+Dust)	Slump Value (mm)	Remarks
1	0%	100	
2	2.50%	90	
3	5%	70	
4	7.50%	65	

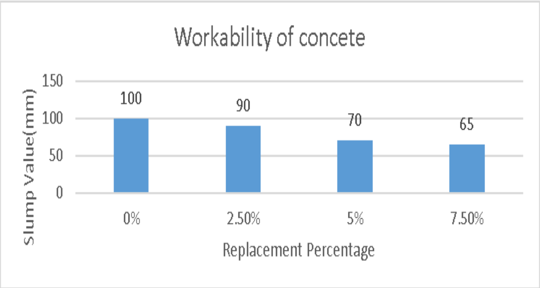


Figure 3: Workability test of concrete

Chapter 5: Conclusion and Recommendations

Based on the limited test results of limited tests, it can be concluded that,

1. The mechanical properties of concrete by partial replacement of cement and fine aggregate by wood ash and sawdust powder provides good flexure strength than ordinary concrete up to certain limit only but did not provide good strength in compression.
2. With the replacement of 2.5% and 5%, flexural strength increased by 10% and 6%. But when the replacement percentage was 7.5% then flexural strength was reduced by 17% than that of ordinary concrete.
3. Compressive strength was reduced by 13%, 29% and 52% than that of ordinary concrete with the replacement of 2.5%, 5% and 7.5%. The result obtained was within the limit of provision in codes up to 5% replacement.
4. Compressive strength of concrete decreased with the addition of wood ash and sawdust powder from the beginning, while the flexure strength started to decrease beyond 5% replacement of wood ash and sawdust powder, which have properties of lower binding ability

and increase concrete porosity. Therefore, it influences the overall physical and mechanical characteristics of the concrete.

5. The optimal replent percentage of wooden ash and saw dust powder appears to be around 5% balancing environmental benefits with good structural performance. Beyond 5%, both compressive and flexural strength declined significantly due to decreased in binding capacity and poor inter-particle bonding.
6. Increased dosage of wooden ash and saw dust powder in the concrete mix resulted in reduced workability leading to harsh mix.
7. Water absorption increases with higher wooden ash and sawdust powder content and cure time due to porous nature.

Recommendation for future research:

Based on the experimental results and observations, the following recommendations are made:

1. More work needs to be done, either to confirm some observed behavior, or extend to areas that are not yet covered such as cracking pattern, stiffness, shear behavior development of strength relations and bond characteristics.
2. Further investigation is necessary in long term strength development and durability of concrete with wooden ash and saw dust powder.
3. Behavior of concrete at elevated temperature and elevated structure exposed to weather is also recommended.

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