Influence of Nanosilica on Workability and Compressive Strength of Wood Ash Cement Concrete

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Abstract

Studies have revealed that wood ash cement concrete just like other pozzolanic cement concrete has lower early strength compared to plain cement concrete. Nanoparticles have been found to improve the early strength of concrete due to its small size and large surface area. This paper reports the influence of nanosilica on the workability and compressive strength of wood ash cement concrete. Wood ash was obtained as a waste product from Ladoke Akintola University of Technology (LAUTECH) bread bakery, Ogbomoso. Biological synthesis of nanosilica using kola Pod extract and silica precursor (1:5) was conducted at Nanotechnology research group laboratory at LAUTECH. The chemical composition, specific gravity and particle size distribution of wood ash, fine and coarse aggregate used were determined. Concrete with 10% wood ash replacement for cement was produced using 1:2:4 mix proportion and water to binder ratio of 0.5. Nanosilica was added at 0.5, 1.0, 1.5 and 2.0% levels. Concrete with no wood ash and nanosilica served as the control. Workability and compressive strength of the plain and composite concrete were determined. The results showed that concrete workability was enhanced with introduction of nanosilica. The compressive strength also increased with addition of nanosilica. Maximum compressive strength of 27.53MP was achieved at 90 days with 1.5% nanosilica addition. It was concluded that nanosilica enhanced workability and improved both early and later strength development in wood ash concrete with 1.5% as the optimum addition.

Keywords: Woodash, cement, concrete, Nanosilica, Workability and Compressive strength.

Introduction

Concrete is a versatile and relatively economical construction material with unlimited application in buildings and other civil engineering structures. It is a composite mixture of cement, fine aggregate (sand), coarse aggregate (gravel or crushed stone) and sometimes chemical admixtures or mineral additives. Pozzolans can be used as supplementary cementitious materials (SCM) or as mineral additives in Concrete.

Several researchers have investigated the use of pozzolan such as coal fly ash, rice husk ash, corn cob ash, sawdust ash, wood ash, etc. to partially replace energy intensive cement (with non-environmental friendly by-product) in the production of concrete (Antiohos, 2005; Raheem and Kareem, 2017; Adesanya and Raheem, 2009; 2010; Raheem *et al.*, 2012; Raheem and Adenuga, 2013). In finely divided form and in the presence of water, these SCM react with calcium hydroxide a by-product of cement hydration to form calcium-silicate-hydrate and other cementitious hydrate compounds. Studies have shown that concrete containing pozzolan have lower early age strength as compared to plain cement concrete but shows greater improvement than plain cement concrete at later ages (Adesanya and Raheem, 2009; Raheem *et al.*, 2012; Chowdhury *et al.*, 2015).

Wood ash is a product of wood combustion that possesses pozzolanic property. Several researchers had worked on partial replacement of cement in concrete with wood ash (Abdullahi, 2006; Udoeyo, 2006; Siddique, 2012; Raheem and Adenuga, 2013; Chowdhury *et al.*, 2015). All the studies showed that the inclusion of wood ash as partial replacement for cement has adverse effect on some properties of concrete. A study by Abdullahi (2006) showed that the compressive strength of plain cement concrete (23.96MPa) was greater than that of wood ash concrete (14.13MPa) at age 28 days. However, at 60-day

curing age, the compressive strength of wood ash concrete increased by 32% compared to 0.79% increase in plain cement concrete. Also, according to Chowdhury *et al.* (2015), splitting tensile strength of wood ash concrete decreased with increase in percentage of wood ash. In the same vein, Udoeyo *et al.* (2006) asserted that concrete specimens absorbed more water as the wood ash content increased. These negative effects of partial replacement of cement with wood ash need to be tackled so as to maintain the integrity of the concrete. This led us to the incorporation of nanoparticles in pozzolan concrete.

Nanoparticles are highly reactive materials which have been used to improve the structural efficiency, durability and strength of concrete. The addition of nanoparticles accelerates chemical reaction during initial hydration thereby strengthening cement composites. The addition of TiO_2 , Al_2O_3 , SiO_2 and Fe_2O_3 nano particles have been shown to improve concrete properties by creating a more compact microstructure which not only decrease permeability, but also enhance mechanical properties (Sikora *et al.* 2018; Mahender and Ashok, 2017; Bera *et al.*, 2012; Nazari and Riahi, 2011a; 2011b; 2011c). According to Nazari and Riachi (2011c), addition of nano silica up to 4% increased the early age compressive strength of concrete. The study showed that concrete incorporated with 4% of nano silica showed improvement of 49%, 101% and 74% relative to conventional concrete at 2-day, 7-day and 28-day curing ages, respectively. Nazari and Riahi (2011a) reported that concrete specimens containing Al_2O_3 nanoparticles have significantly higher compressive strength when compared with conventional concrete at every age of curing. In this study, the influence of nanosilica on workability and compressive strength of wood ash cement concrete was investigated.

Materials and Methods

Materials

Ordinary Portland cement of grade 42.5 in accordance with (BS 12: 1996) was used. Natural river sand obtained locally was used as fine aggregates. Crushed granite stone from local quarries was used as coarse aggregate with maximum size of 19mm. Wood ash was obtained as a waste product from Ladoke Akintola University of Technology (LAUTECH) Ogbomoso, Nigeria, bread bakery. The wood ash was collected the bakery with the aid of hand scoop from the exhaust of the oven after the fuel has been completely burnt. Biological synthesis of nanosilica using cola pod extract and silica precursor (1:5) was conducted at nanotechnology research group laboratory at LAUTECH.

Testing of Materials

The collected wood ash was analyzed by (Raheem and Adenuga, 2013) at West Africa Portland Cement Company (WAPCO) Sagamu, Ogun state, Nigeria, to determine its chemical composition. The analysis of the ash was carried out using X-ray Fluorescence Analyser (Model QX 1279). The specific gravity of the ash was also determined.

Sieve analysis was performed to determine the particle size distribution of the wood ash, fine and coarse aggregates. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) of the fine and coarse aggregates were obtained so as to classify them and assess their suitability.

Specimen Preparation

The concrete mix ratio used was 1:2:4 with water-cement ratio of 0.5. Six mix proportions were prepared. Sample A was normal concrete with no wood ash and nanosilica. Sample B was prepared by replacing 10% of cement with wood ash. Sample C, D, E and F had 0.5, 1, 1.5 and 2% of nanosilica by weight of cement, respectively added to the concrete mix. Table 1 shows the mix proportion by weight of the materials in each sample.

Table 1: Proportioning of Concrete

Sample	Percentage of Nano silica (%)	Cement (kg)	Wood ash (kg)	fine aggregate (kg)	Coarse aggregate (kg)	Nano silica (kg)
A	0.00	25.63	0.00	51.25	102.5	0.00
B	0.00	23.07	2.56	51.25	102.5	0.00
C	0.50	23.07	2.56	51.25	102.5	0.13
D	1.00	23.07	2.56	51.25	102.5	0.26
E	1.50	23.07	2.56	51.25	102.5	0.39
F	2.00	23.07	2.56	51.25	102.5	0.52

Testing of specimens

Workability of each sample was assessed by conducting slump and compacting factor tests in accordance with (BS 1881: Part 102-83) and (BS 1881: Part 103-83), respectively. Compressive strength test was carried out on 150mm cube concrete specimens. The specimens were cast in three layers, each layer was tamped uniformly across the cross-section of each layer with 25 strokes of the tamping rod. The top layer of each mould was leveled and smoothed and the outside surface cleaned. All specimens were demoulded after 24hours and cured in water. The compressive strength was determined at curing ages 3, 7, 28 and 56 days using compression machine with maximum capacity of 1500kN (Model 50- C34AC and Serial no 02094910). The compressive strength of each sample was the average of three specimens.

Results and Discussion

Chemical Composition

The elemental oxides present in the wood ash sample are shown in Table 2. The result indicated that the wood ash had combined percentages of SiO_2 , Al_2O_3 and Fe_2O_3 of 73%. This result is similar to that of Chowdhury *et al.* (2015) with wood ash having combined silica, alumina and ferric oxide of 71.79%. This indicates that the present wood ash is a good pozzolanic material in accordance with the requirements in ASTM C 618. As reported by Jerath and Hanson (2007), wood ash from bread bakery falls under the category of class F fly ash since the sum of $(\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$ is greater than 70%.

Table 2: Chemical Composition of Wood Ash

Chemical Constituents	Percentage Composition (%)			
	Sample 1	Sample 2	Sample 3	Average
SiO_2	61.12	62.75	61.74	61.18
Al_2O_3	7.05	7.95	7.57	7.52
Fe_2O_3	3.22	2.91	3.44	3.19
CaO	10.56	12.94	11.88	11.77
MgO	2.34	2.00	3.11	2.48
SO_3	1.84	1.80	1.82	1.82
Na_2O	1.15	1.00	1.11	1.09
K_2O	3.56	4.11	3.75	3.81
CaCO_3	6.12	6.22	6.31	6.22
LOI	2.95	3.20	2.99	3.05
LSF	1.2	1.37	1.27	1.28
SR	4.15	4.25	4.56	4.32
AR	7.48	7.56	7.62	7.55
Total $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	71.39	73.61	72.75	72.58

Specific Gravity

Table 3 shows the results for the specific gravity of wood ash. The specific gravity of wood ash was found to be 2.28. This result is within the range of values obtained by (Udoeyo *et al.*, 2006).

Table 3: Wood Ash Specific gravity

	Trial 1	Trial 2	Trial 3	Average
Mass of density bottle (g)	25	25	25	25
Mass of density bottle + wood ash (g)	34	34	32	33.33
Mass of density bottle + wood ash + water (g)	77	77	76	76.67
Mass of density bottle + water (g)	72	72	72	72
Specific gravity	2.25	2.25	2.33	2.28

Sieve Analysis

The results of the sieve analysis for wood ash, fine and coarse aggregates is presented in figure 1. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) of the wood ash are 2.86 and 1.23 respectively, thus, the wood ash is classified as uniformly graded (Smith and Smith, 1998). Similarly, the C_u and C_c for fine aggregates and coarse aggregates are 4.11, 1.09 and 4.10, 1.01 respectively. The coefficient of uniformity gives an indication of the spread of particles sizes (Bowles, 1992). Since both values of the coefficient of uniformity fall between 1.0 and 5.0, it can be concluded that the fine and coarse aggregates are uniformly graded and are therefore suitable for making good concrete.

Figure 1: Particle Size distribution graph of Wood Ash, Fine Aggregate and Coarse Aggregate.

Workability

The results of the slump and compacting factor tests are presented in Table 4. It is evident from the results that wood ash concrete has lower workability than plain concrete at the same water-binder ratio. Plain cement concrete without wood ash and nanosilica (Sample A) had a slump of 65mm and compacting

factor of 0.94. Sample B with 10% Wood ash content and without nano silica had a slump value of 45mm and compacting factor value of 0.91. This shows that sample A is more workable than sample B. This is in line with the findings of Udoeyo *et al.* (2006) and Abdullahi (2006) that wood ash cement concrete requires additional water relative to plain cement concrete to achieve a reasonable workability. However, addition of more water is detrimental to the strength property of concrete. This problem is solved with the incorporation of nanosilica into the wood ash concrete. With the addition of 0.5% nanosilica into the wood ash concrete (Sample C), the slump and compacting factors increased to 50mm and 0.94, respectively. The trend continued, with wood ash concrete containing 2.0% nanosilica having the highest slump and compacting factor of 70mm and 0.97, respectively. Thus, the workability of wood ash concrete increased with the introduction of nanosilica into the mix.

Table 4: Slump and Compacting Factor of Wood Ash Cement Concrete

Sample	Slump (mm)	Compacting factor
A	65	0.94
B	45	0.91
C	50	0.94
D	60	0.95
E	65	0.96
F	70	0.97

Compressive Strength

The compressive strength of concrete samples is presented in Figure 2. It can be observed from the figure that the addition of nanosilica generally increased the compressive strength at both early and later curing ages.

At 3 days, sample B had the lowest compressive strength (10.74MPa) below plain cement concrete (10.89MPa). The compressive strength of wood ash concrete increased with increase in percentage of nanosilica up to 1.5% addition. Samples C, D and E with 0.5, 1.0 and 1.5% nanosilica addition had compressive strength of 10.96, 11.12 and 12.59MPa, respectively. However, the strength dropped at 2% addition to 11.19MPa. The increase in compressive strength is due to faster pozzolanic reactivity of nanoparticles, in the presence of Ca(OH), making the microstructure denser (Ghafari *et al.* (2014). According to Lin *et al.* (2008), the incorporation of nanosilica can accelerate the hydration process of C₃S clinker phase due to the large and highly reactive surface of nanoparticles. The decrease in strength at 2% nanosilica addition could be attributed to improper dispersion of nanoparticles in the mixture. As reported by Ghafari *et al.* (2014), when nanoparticles are added in excess to the mixture, these are not uniformly dispersed in the cement paste and as a consequence, weak areas appear in the concrete due to agglomeration.

Similar trends were observed at 7 and 28 days. The compressive strength of all the samples improved relative to the 3-day strengths. At 7 days, sample B had the lowest compressive strength (11.41MPa) below that of sample A (12.00MPa). The compressive strength then increased with increase in percentage of nanosilica up to 1.5%. Sample E had the highest compressive strength (17.33MPa). At 28 days, sample A still had higher compressive strength than sample B. Addition of nanosilica at 0.5% improved the compressive strength of concrete over both sample A and sample B concretes. At 1% addition, there was an insignificant (0.22%) drop in strength. Addition of nanosilica at 1.5% gave the highest compressive strength value (21.63MPa) while 2.0% addition has a reduced compressive strength of 14.11 MPa.

There was an anomalous reduction in 56 days compressive strengths of samples A and B relative to their 28 days strengths. This deviation can be attributed to experimental random errors. However, similar trend was followed as in previous curing ages. The compressive strength increased with increase in percentage

of nanosilica addition up to 1.5% before dropping at 2.0% addition. At 90 days, there was rapid increase in compressive strength of all wood ash cement concrete samples (B, C, D, E, F) over that of 56 days. The difference between the compressive strength of sample B (15.97 MPa) and sample A (16.56 MPa) is lower compared to earlier curing ages. The gain in compressive strength is due to pozzolanic reaction of wood ash cement concrete at later ages. The compressive strength increased from 17.42 MPa at 0.5% nanosilica addition to 21.25 MPa at 1.0% and 27.53 MPa at 1.5% before dropping to 22.61 MPa at 2.0%. Recent study by Saloma *et al.* (2015), stated that rapid development of compressive strength of concrete with nano silica is an indication that the nanosilica not only serve as a filler to increase density of the micro structure *et al.*, but also acts as an activator in the hydration reaction.

It is pertinent to note that improvement in strength of wood ash cement concrete over plain concrete was made possible at lower and higher curing ages by the addition of nanosilica up to the optimum level of 1.5%. This is an improvement over the well-known characteristics of pozzolan cement concrete that only gain strength at higher curing ages. Thus, the low reactivity of wood ash cement concrete, especially at lower curing ages was enhanced by the incorporation of nanosilica into the mixture.

Figure 2: Effect of nanosilica on the compressive strength of concrete made with cement containing 10% wood ash

Conclusion

From the results of the various tests performed, the following conclusions were drawn:

- i. Wood ash cement concrete becomes more workable with the addition of nanosilica into the mixture.
- ii. Nanosilica improved the early and later compressive strength of wood ash cement concrete.
- iii. The optimum level of nanosilica addition is at 1.5%, for concrete containing 10% WA replacement for cement.

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