

Pozzolanic Properties of White Cowpea Husk Ash

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Abstract. This research attempts to empirically investigate the pozzolanic properties of White Cowpea Husk Ash (WCHA), an agricultural biomass waste, at different percentages of its use as partial replacement of cement in concrete. WCHA was obtained after the calcination of white cowpea husk for 3 hours at 550°C. X-ray Florescence (XRF) analysis performed revealed that the sample of WCHA is a Class C pozzolana, which contains 65.4% of the combination of SiO₂, Al₂O₃, and Fe₂O₃. The WCHA shows increase in consistency with increase in the WCHA content. This was attributed to the high Loss of Ignition (LOI) of WCHA compared to that of the cement. In addition, the results indicated that the initial and final setting time of WCHA – Cement blended concrete increase with increase in the WCHA content. The delay in setting times of WCHA-Cement paste could be attributable to the slower pozzolanic reaction. The density of the concrete decreased as the WCHA content increases. Generally the compressive strength of the WCHA concrete increased with increase in curing age and decreases as the WCHA content increased from a strength of 28.6 to 20.0 N/mm² giving a percentage reduction of 30.1 %. The strength reduction is also attributed to the modification of the bonding properties of the binders' hydrates. However, the 28 days compressive strength of concrete with up to 10 % WCHA content (26.4 N/mm²) satisfied the design characteristic strength of 25 N/mm². Beyond this limit, the compressive strength of the concrete fell below the design strength. Hence, 10 % WCHA could be regarded as the optimum dose for grade 25 concrete.

Keywords: Concrete, Compressive Strength, White Cowpea Husk Ash (WCHA), X-ray Florescence.

1. Introduction

Concrete is reported to be one of the most consumed construction material by man with a worldwide consumption estimated in 2006 of between 21 and 31 billion tonnes (European Concrete, 2009; Odeyemi et al., 2020). Concrete is made from coarse aggregates (gravel or crushed stone), fine aggregates (sand), water, cement and admixtures (European Concrete, 2009).

Cement on the other hand is the most important ingredient in concrete, whose production contributes significantly to the global amount of carbon dioxide (CO₂) emissions in our environment which is known to be highly inimical and hazardous to human health, making up approximately 2.4 percent of global CO₂ emissions from industrial and energy sources (Marland et al., 1989). However, gas emission during cement production can be reduced by the utilization of mineral additives in concrete (Malhotra and Mehta, 2002 and Awang et al., 2016). There have been extensive studies done on the use of the more common mineral additives in concrete such as; Rice Husk Ash (RHA) (Habeeb et al, 2009; Ogork et al, 2010; Atan and Awang, 2011; Aboshio et al, 2018), fine limestone powder (Felekoglu, 2007; Ye et al, 2007; Esping, 2008), pulverized-fuel ash (Sukumar et al., 2008; Liu, 2010; Siddique, 2011), silica fume (Yazici, 2008; Gesoglu et al., 2009; Turkel, 2009). However, lesser interests are shown on other types of mineral additives due to various factors such as: the availability of certain mineral additives, transportation

problems and heterogeneity of the additives chemical components (Atan and Awang, 2011). A total of 3.3 million tonnes of cowpea dry grain were produced worldwide in 2000 as estimated by Food Agriculture Organization (FAO) (IITA Research, 2001). Most cowpeas are grown on the African continent, particularly in Nigeria and Niger, which account for 66% of world production (Singh et al, 1997). Brazil is the world's second-leading producer of cowpea seed, accounting for 17% of annual cowpea production (Gómez, 2004). Large quantity of pods is generated from production of cowpea. Utilization of WCHA as an additive or partial replacement to cement in concrete production will enhance more cultivation of cowpea. However, limited or no information is available on its previous utilization in concrete

2. Materials and methods

The materials used for the research include the following:

2.1. White Cowpea Husk Ash

WCHA was collected from a farmland in Gezawa Local Government Area where there is mass production of cowpea. Burning of white cowpea (beans) husk was carried out under controlled temperature of between 500 - 700 °C using the incinerator available in School of Technology, Kano State Polytechnic, Kano State, Nigeria. The ash was ground and sieved to produce a finer ash.

2.1.1. Cement

The Cement used for the investigation is manufactured by Dangote cement company (CEM II/A-L, 42.5N).

2.1.2. Aggregate

Clean river sand (fine aggregate) and crushed rock (coarse aggregate) were used throughout the research. The coarse aggregate size was 20mm and both conformed to BS 882:1992. The WCHA before and after calcination are shown in plate 1a and 1b respectively.



Plate 1a: Cowpea Pod before Calcination



Plate 1b: Calcined Cowpea Pod Ash

The fresh concrete was produced manually following the laid down procedure given in BS 1881-125 (2013). Cement, sand and crushed rock was proportioned by weight as shown in Table 1 and mixed homogeneously using water cement ratio obtained from the mix design. Fresh concrete with 0, 5, 10, 15, 20 and 25 % WCHA replacement of cement by weight respectively were produced following same procedure and treatment. The fresh property of the concrete using slump test was checked and the concrete thereafter was cast in clean and oiled moulds for compressive strength, splitting tensile and flexural strengths. After allowing the concrete to harden for 24 hours, the cubes were demoulded and dipped in a curing tank filled with water until the testing period was reached. Plate 2a and 2b shows the batching procedure for the concrete.

Table 1. Material proportioning for concrete

% WCPA	WCHA (kg/m ³)	Cement (kg/m ³)	Sand (kg/m ³)	Granite (kg/m ³)	Water (kg/m ³)
0	0	380	625	1165	190
5	19	361	625	1165	190
10	38	342	625	1165	190
15	57	323	625	1165	190
20	76	304	625	1165	190
25	95	285	625	1165	190

**Plate 2a and 2b: Batching of Material**

3. Results and discussion

3.1. Tests on WCHA, Cement and Aggregate

The following tests were carried out on various material samples; XRF analysis, specific gravity, consistency, setting time and particle size distribution. The tests were carried out in accordance with the provision by various standard codes discussed in the Materials and Methods section. The results obtained are presented in Tables 2 – 3 and Figures 1 - 6.

Table 2. Oxide Composition using XRF analysis

Oxides	WCHA (%)	CEMENT (%)
SiO ₂	41.641	20.171
Al ₂ O ₃	13.682	4.101
Fe ₂ O ₃	10.066	3.899
CaO	20.542	63.871
MgO	2.001	2.105
SO ₃	1.401	2.1
Na ₂ O	0.234	0.011
K ₂ O	1.135	0.938
P ₂ O ₅	1.879	0.117
Cl	0.086	0.098
TiO ₂	0.287	0.209
Cr ₂ O ₃	0.001	0.003
Mn ₂ O ₃	0.02	0.036
ZnO	0.237	0.011
SrO	0.011	0.232
LoI	6.773	2.093

The oxide composition presented in Table 2 shows that the cement has CaO + SiO₂: 84.042 (≥ 50 %), CaO/SiO₂: 3.166 (≥ 2 %), SO₃: 2.1 (≤ 3.5 %), MgO: 2.105 (≤ 5.0 %), Cl: 0.098 (≤ 0.1 %). This indicates that the cement satisfied the recommended limit for CEM II 42.5N class given in ASTM C618 (2005). In addition, the sum SiO₂ + Al₂O₃ + Fe₂O₃ for WCPA is 65.389 % this is less than the limit (≥ 70 %) provided by ASTM C618 (2005). However, the material could be regarded as class

C pozzolana since the requirements SiO_2 : 41.641 (≥ 39.90), $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$: 65.389 ($\geq 50\%$), SO_3 : 1.401 ($\leq 5.0\%$), Na_2O : 0.234 (≤ 1.5) was satisfied.

Table 3. Specific Gravities of Concrete Materials

Materials	Values
Cement	3.15
WCHA	2.15
Fine Aggregate	2.69
Coarse Aggregate	2.61

From the specific gravities of concrete materials shown in Table 3, it was deduced that the specific gravity of the cement is within the recommended value of 3.10 - 3.16 for ordinary Portland cement (OPC) (ASTM C 188, 2005). WCHA has a specific gravity of 2.15. This shows that WCHA is less dense than OPC and hence signifying lesser volume of cement required more volume of equal mass of WCHA. The specific gravities of fine and coarse aggregates fall within the specified limit as specified by ACI Education Bulletin, 2007.

3.2. Particle size distribution

The particle size distribution of the aggregates carried out by dry sieving is presented in Figure 1.

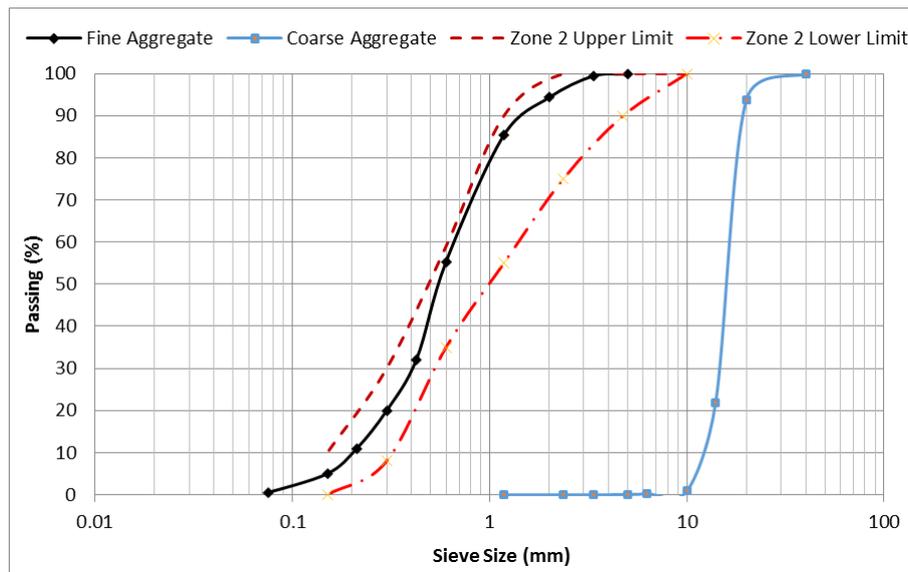


Fig. 1. Particle Size Distribution of Fine and Coarse Aggregates

The result of the particle size distribution of fine aggregate as presented in Figure 1 shows that the fine aggregate has fineness modulus of 2.57 and it belongs to zone II class based on BS EN 12620:2002+A1:2008 grading limits for fine aggregates. The result of the particle size distribution of the coarse aggregates as presented in the figure shows that the coarse aggregate has dominant particle size of 20 mm with only 71.82 and 21.96 % retained and passing 14 mm sieve respectively. Hence, the coarse aggregate could be regarded 20 mm size. In addition, the fineness modulus of the coarse aggregate is 6.97.

3.3. Effect of WCHA on Consistency of Cement Paste

The consistency of cement paste with varied proportion of WCHA is presented in Figure 2. The consistencies ranged from 30 % at 0 % WCPA to 39 % at 25 % WCPA. This suggests that the consistency of the cement paste increases with increase in WCHA content. The increase in consistencies with increase in WCHA content could be due to high LoI of WCHA compared to

that of the cement. This finding is similar to the observations of Ogork et al (2014) and Jaturapitakkul and Roongreung (2003). This result is also linked to the lower specific gravity of WCHA when compared to that of cement (Ogork et al, 2014).

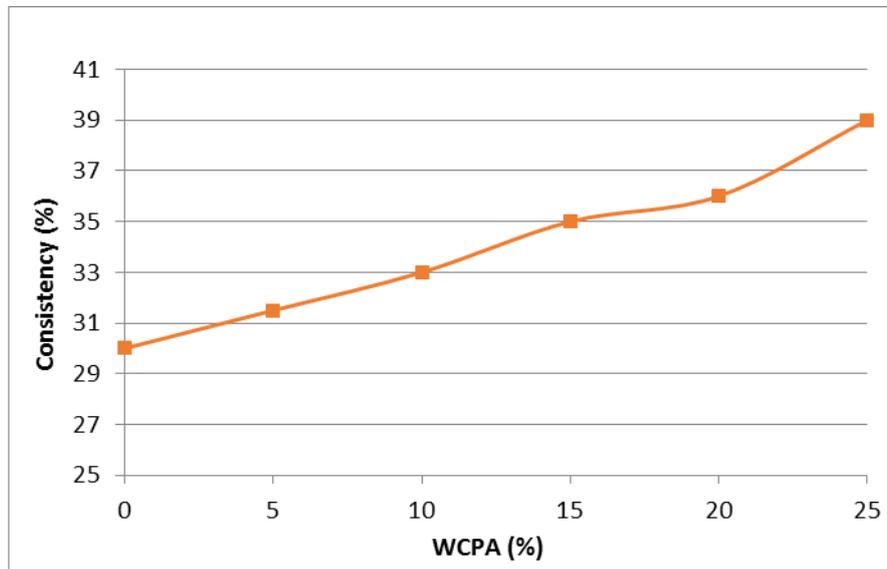


Fig. 2. Consistency of binder with varied proportion of WCPA

3.4. Effect of WCHA on Initial Setting and Final Setting Time of Cement Paste

The initial setting and final setting time of WCHA-Cement paste ranged from 76 to 168 minutes and 172 to 351 minutes respectively for 0 to 25 % WCHA replacement as shown in Figure 3. The initial and final setting time of WCHA-cement is within the allowance specified in BS EN 197-1 (2011) (≥ 60 minutes) and (≤ 10 hours) respectively for 42.5 N graded OPC. In addition, the results indicate that the initial and final setting times of WCPA - Cement paste increase with increase in WCPA content. The delay in setting times of higher percentage content of WCHA-Cement paste could be as a result of the slower pozzolanic reaction (Jaturapitakkul and Roongreung, 2003 and Ogork et al, 2014) of WCHA. In addition, the delay of setting times of WCHA - cement could also be due to lower cement content and dispersion effect provided by the WCHA on the cement particles (Gesoglu and Erdogan, 2007 and Ezziane et al., 2010).

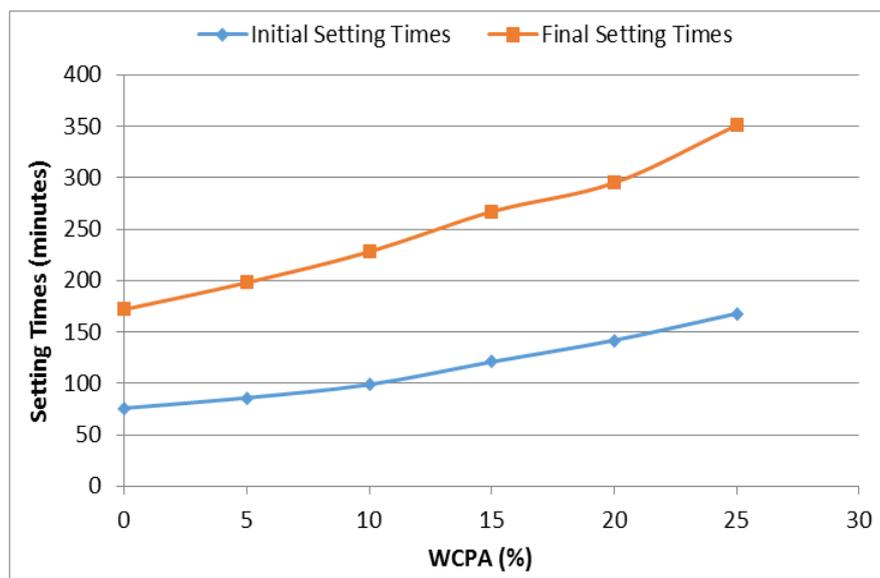


Fig. 3. Setting time with varied proportions of WCPA

3.5. Effect of WCHA on the Properties of Fresh Concrete

The workability of the fresh concrete using slump test method carried out in accordance with BS 1881-102(2000) was used to assess the effect of WCHA on the properties of fresh concrete. The result as presented in Figure 4 shows that the workability of the fresh concrete reduces with increase in WCHA content. The reduction in workability could be as a result of the decrease in fluidity of the mix due to high water demand of WCHA (Obilade, 2014). In addition, the reduction could also be attributed to reduction in density of the mix as WCHA content increases (Said et al., 2014 and Ogork and Auwal, 2016) as well as its fineness modulus as compared to that of cement.

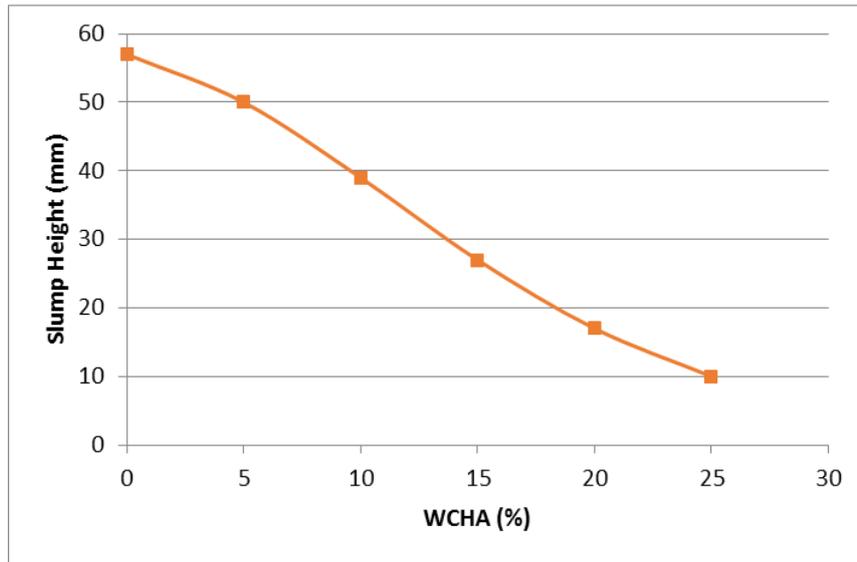


Fig. 4. Workability of WCHA - Concrete

3.6. Effect of WCHA on the Density of Concrete

The effect of WCHA on the density of concrete is shown in Figure 5. The density of the concrete decreased as the WCHA content increases possibly owing to the lower specific gravity of WCHA than that concrete. The peak density is at 5% replacement of WCHA. The density range between 2515 kg/m³ - 2286 kg/m³.

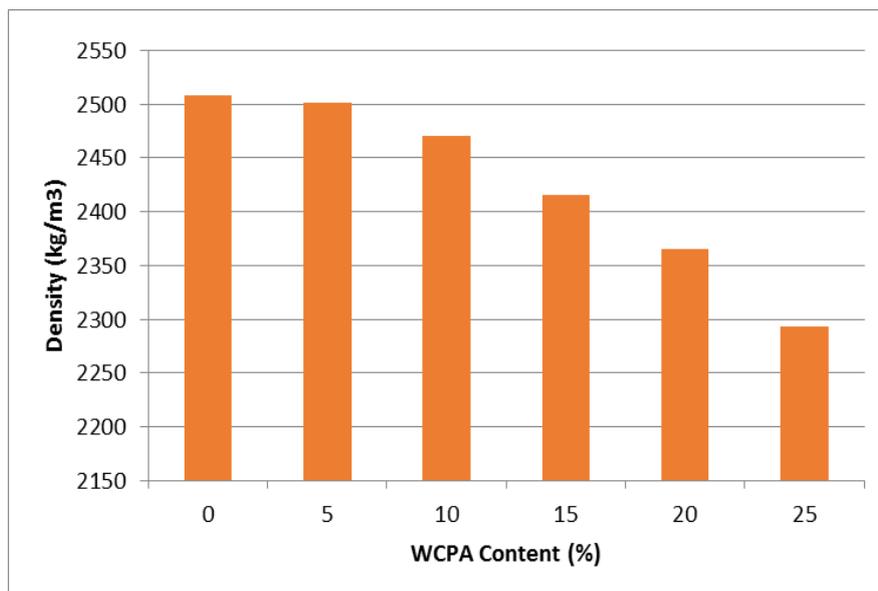


Fig. 5. Effect of WCHA on Density of Concrete

3.7. Effect of WCHA on the Compressive Strength of Concrete

Generally the compressive strength of the WCHA concrete increased with increase in curing age and decreases as the WCHA content increased. The strength declined from 28.6 to 20.0 N/mm² giving a percentage reduction of 30.1 % as shown in Figure 6. The reduction in strength could be attributed to decrease in densities of the concrete as WCHA content increases. The strength reduction could also be as a result of modification of the bonding properties of the binders' hydrates as reported by Phan *et al*, 2001 and Kanema, 2007). However, the 28 days compressive strength of concrete with up to 10 % WCHA content (26.4 N/mm²) satisfies the design characteristic strength of 25 N/mm². Beyond this limit, the compressive strength of the concrete was below the design strength. Hence, 10 % WCPA could be regarded as the optimum dose for grade 25 concrete.

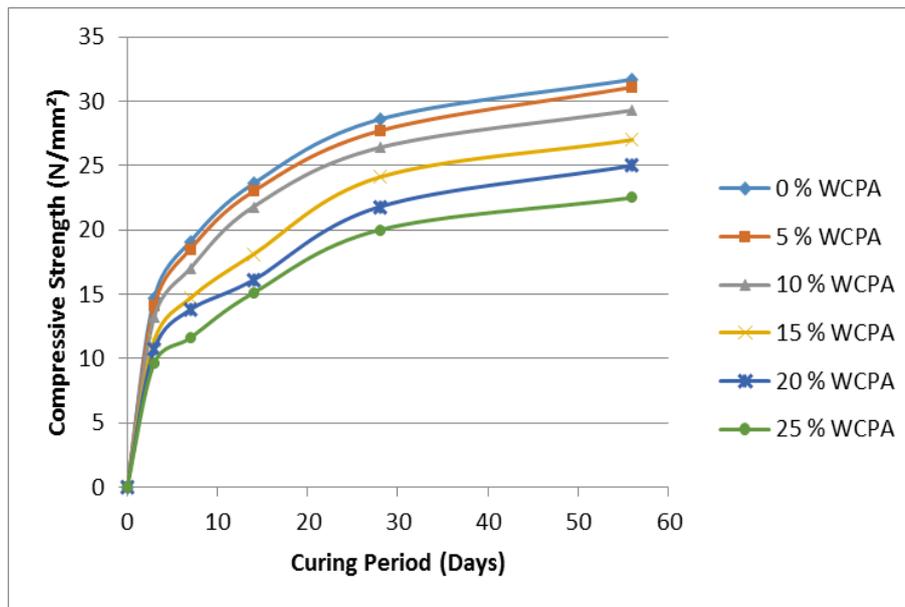


Fig. 6. Compressive Strength of WCHA - Concrete

4. Conclusions

From the oxide composition of WCHA, it can be concluded that WCHA satisfies the requirement for class C pozzolana as provided by ASTM C618. The consistency, initial and final setting time of cement increased with increase in WCHA content. WCHA reduces the workability of a concrete. Grade 25 concrete can be satisfactorily produced using up to 10 % WCHA replacement of cement by weight.

Disclosure statement

No potential conflict of interests of any form regarding the publication of this manuscript is available.

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