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Tensile Strengths of Concrete Containing Sawdust Ash from Different Calcination Methods

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ABSTRACT

This work investigated the tensile strengths of concrete containing sawdust ash from different calcination methods. SawDust Ash (SDA) was produced using three different calcination methods namely: Open Air Calcination (OAC), Stove Calcination (SC), and Furnace Calcination (FC). OPC was partially replaced with SDA from each of the three calcination methods at 5%, 10%, and 15%. Nine concrete cylinders of 150mm x 300mm were produced for each of the three percentage replacement levels of OPC with SDA and for each of the three calcination methods, making a total of eighty one concrete cylinders with OPC-SDA binary blended cement for the three different calcination methods. Nine control concrete cylinders, with same dimensions of 150mm x 300mm, were also produced using 100% OPC. This gives a grand total of 90 concrete cylinders. A mix ratio of 1: 2: 3.5 (blended cement: sand: local stone) was used for the concrete. Batching was by weight and a constant water/cement ratio of 0.6 was used. All the concrete cylinders were cured in water by immersion. Three concrete cylinders from each of the three SDA calcination methods and for each of the three percentage replacement levels of OPC with pozzolan, as well as three control concrete cylinders were tested for saturated surface dry bulk density and crushed to obtain their split tensile strengths at 28, 90, and 150 days of curing. Excel Spreadsheet Regression Analysis was used to develop empirical models for predicting the split tensile strengths of OPC-SDA concrete for each of the three calcination methods. It was found that Split tensile strength values for FC were much greater than those for OAC and SC for all the days of curing and all percentages of replacement of OPC with SDA. The control split tensile strength value rose to 1.34N/mm2 at 90 days and 1.61N/mm2 at 150 days whereas the greatest 90 and 150-day values were 1.10N/mm2 and 1.51N/mm2 respectively for OAC and 1.29N/mm2 and 1.70N/mm2 respectively for SC. The 28-day values for FC were comparable to the control values for 5% and 10% replacement and increased rapidly to exceed the control values at 90 and 150 days. Therefore, OPC-SDA blended cement concrete with SDA obtained from FC could be used for all civil engineering works at 5-10% OPC replacement while OPC-SDA blended cement concrete with SDA obtained from FC at 15% OPC replacement and with SDA obtained from OAC and SC at 5-10% OPC replacement could be used for low strength civil engineering works where early loading of the structural members are not required. The models developed for FC, OAC, and SC methods were tested using t-test analysis and found to be adequate for predicting the split tensile strength values of OPC- SDA binary blended cement concrete at 28-150 days of curing and for 5-15% replacement of OPC with SDA, using SDA obtained from any of the three calcination methods.

Keywords: Concrete, Split Tensile Strength, Rice Husk Ash, Furnace Calcination, Open Air Calcination, Stove Calcination.

I. INTRODUCTION

Cementitious binders are vital for all types of construction activities using concrete. Therefore, researchers have intensified efforts at sourcing local materials that could be used as partial replacement for Ordinary Portland Cement (OPC) in order to reduce the cost of building and civil engineering works. Bakar, Putrajaya, and Abdulaziz (2010) reported that supplementary cementitious materials have been proven to be effective in meeting most of the requirements of durable concrete such that blended cements are now used in many parts of the world. Calcium hydroxide is obtained as one of the hydration products of Ordinary Portland Cement (OPC). It is responsible for the deterioration of concrete. When blended with Portland cement, a pozzolanic material reacts with the calcium hydroxide to produce additional calcium-silicate-hydrate (C-S-H), which is the main cementing component. Therefore, the pozzolanic material serves to reduce the quantity of the deleterious calcium hydroxide as well as increase the quantity of the beneficial calcium-silicate-hydrate. Dwivedia et al. (2006) reported that the cementing quality is enhanced if a good pozzolanic material is blended in suitable quantity with OPC.

Industrial waste pozzolans such as fly ash and silica fume are already widely used in many countries (Cisse and Laquerbe, 2000). Attempts are also being made to produce and use pozzolanic agricultural by-product ashes such as rice husk ash (RHA) and saw dust ash (SDA) commercially in some countries. Malhotra and Mehta (2004) found that ground RHA with finer particle size than OPC improves concrete properties, including that higher substitution amounts results in lower water absorption values and the addition of RHA causes an increase in the strength of concrete. Ghassan and Hilmi (2010) investigated the properties of rice husk ash (RHA) produced by using a ferro-cement furnace and discovered that incorporation of RHA in concrete increased water demand and that RHA concrete gave excellent improvement in strength for 10% replacement. Elinwa, Ejeh, and Akpabio (2005) found that saw dust ash can be used in combination with metakaolin as a ternary blend with 3% added to act as an admixture in concrete. Elinwa, Ejeh, and Mamuda (2008) and Elinwa and Abdukadir (2011) have also investigated the suitability of saw dust ash as a pozzolanic material and found that it could be used in binary combination with OPC to improve the properties of cement composites. Recent studies by Ettu et al. (2013a), Ettu et al. (2013b), Ettu et al. (2013c) and Ettu et al. (2013d) have confirmed the suitability of Nigerian RHA and SDA as pozzolanic materials for producing concrete, sandcrete, or soilcrete.

Fadzil et al. (2008) studied the properties of ternary blended cementitious (TBC) systems containing OPC, ground Malaysian RHA, and fly ash. They found that at long-term period, the compressive strength of TBC concrete was comparable to the control mixes even at OPC replacement of up to 40% with the pozzolanic material. Zhang et al. (1996) studied the effect of incorporation of RHA on the hydration, microstructure and interfacial zone between the aggregate and paste. Based on the investigation, they concluded that: (i) Calcium hydroxide and calcium silicate hydrate were the major hydration and reaction products in the RHA paste; and (ii) The porosity and amount of calcium hydroxide in the interfacial zone were reduced by the incorporation of RHA in concrete. The width of the interfacial zone between the aggregate and the cement paste was also reduced in comparison with that of the control Portland cement composite. Saraswathy and Ha-won (2007) studied the corrosion performance of rice husk ash blended concrete and concluded that RHA as a pozzolan in concrete increases the strength of concrete against cracking. Studies by Kartini et al. (2005), Kartini et al. (2006), Kartini et al. (2007), Gambhir (2006), and Hwang and Chandra (1997) showed that the outstanding technical benefit of incorporating cement replacement materials in concrete is that they significantly improve the durability properties of concrete to various chemical attack due to reduced permeability arising from a pore refining process.

The morphology of the resultant silica from calcination of agricultural by-product pozzolans has been found to be a function of the temperature and degree of control of the combustion process (Nehdi et al., 2003; Ru-shan et al., 2015). Nehdi et al. (2003) state that amorphous silica with high reactivity is produced under controlled combustion conditions and that silica in RHA can remain in amorphous form at combustion temperatures of up to 900^0C if the combustion time is less than one hour, whereas crystalline silica is produced at 1000^0C with combustion time greater than five minutes. Frías et al. (2005) studied the influence of calcining temperature as well as clay content in the pozzolanic activity of sugar cane straw-clay ashes-lime systems and found that all calcined samples showed very high pozzolanic activity and the fixation rate of lime (pozzolanic reaction) varied with calcining temperature and clay content. Ru-shan et al. (2015) showed that in muffle furnace 600^0C is the appropriate temperature for rice husk ash preparation as it produces RHA with large specific surface area due to the existence of nanoscale and amorphous silica.

Tensile strength behavior of concrete is of interest because concrete structures are subjected not only to compressive forces but also to tensile forces. The knowledge of tensile strength is used to estimate the load under which cracking will develop. This is especially useful in the design of concrete pavement, airfield runway, and railway track (Gambhir, 2006).

Since the use of pozzolanic agricultural by-products as partial replacement to OPC in making blended cement concrete is becoming more and more acceptable, there arises a need to produce agricultural by-product ashes using calcination processes easily adaptable to dwellers in various communities in South Eastern Nigeria where they are abundantly found. Hence, this work investigated the tensile strengths of concrete containing SDA produced from different calcination methods that could be replicated by local community dwellers.

II. METHODS AND MATERIAL

Saw dust was obtained from timber milling factories in Owerri, South-Eastern Nigeria. The material was air-dried and calcined into ashes using three different methods namely: Open air calcination (OAC), Stove calcination (SC) and Furnace calcination (FC). The open air combustion was done in an open chamber at an uncontrolled degree of temperature ranging between 450^oC and 600^oC. The stove combustion was done using improvised cylindrical stove commonly used by local dwellers at a temperature generally below 700^oC. The furnace burning was done using local pit crucible furnace fired with coke at a temperature of 600-800^oC. Temperature was measured with a Type-K thermocouple in all the three calcination methods. The rice husk ash (RHA) was sieved and large particles retained on the 600μm sieve were discarded while those passing the sieve were used for this work. No grinding or any special additional treatment was applied to improve the quality of the ash and enhance its pozzolanicity because the researchers wanted to utilize simple processes that could be easily replicated by local community dwellers.

The SDA obtained from OAC had bulk density, specific gravity, and fineness modulus of $680kg/m^3$, 1.72, and 1.66 respectively. Corresponding values for that obtained from SC were $700kg/m^3$, 1.74, and 1.60 respectively, while values for that obtained from FC were $710kg/m^3$, 1.85, and 1.76 respectively. Other materials used for this work are Ordinary Portland Cement (OPC) with a bulk density of $1660kg/m^3$ and specific gravity of 3.06; river sand free from debris and organic materials with a bulk density of $1710kg/m^3$, specific gravity of 2.64, and fineness modulus of 3.35; crushed local stone of 20mm nominal size free from impurities with a bulk density of $1490kg/m^3$, specific gravity of 2.76 and fineness modulus of 5.34; and water free from organic impurities.

A simple form of pozzolanicity test was carried out for the sawdust ashes. It consists of mixing 20g of the ash with 100ml of Calcium hydroxide solution [$Ca(OH)_2$] in a 50ml burette, and titrating samples of the mixture against 0.1M of H_2SO_4 solution at time intervals of 30mins, 60mins, 90mins, and 120mins respectively using Methyl orange as indicator at normal temperature. The mixture was stirred using a Labnet Orbit shaker (model 1000). The titre value (volume of acid required to neutralize the constant volume of calcium hydroxide-ash mixture) was found to reduce with time, confirming the ash as a pozzolana that fixed more and more of the calcium hydroxide, thereby reducing the alkalinity of the mixture.

The chemical analysis of the ashes showed that the sum of SiO_2, Al_2O_3, and Fe_2O_3 was 50.03% for OAC, 57.17% for SC, and 82.02% for FC, indicating that only SDA produced from FC satisfied the ASTM requirement that the sum of SiO_2, Al_2O_3, and Fe_2O_3 should be not less than 70% for pozzolans. However, since simple pozzolanic test confirm sawdust ashes produced from OAC and SC to be pozzolanic, these ashes could be classed as lower quality pozzolans.

A mix ratio of 1: 2: 3.5 (blended cement: sand: local stone) was used for the concrete. Batching was by weight and a constant water/cement ratio of 0.6 was used. Mixing was done manually on a smooth concrete pavement. The SDA was thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the fine aggregate and coarse aggregate, also at the required proportions. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity. OPC was partially replaced with SDA from each of the three calcination methods at 5%, 10%, and 15%. Nine concrete cylinders of 150mm x 300mm were produced for each of the three perecentage replacement levels of OPC with SDA and for each of the three calcination methods, making a total of eighty one concrete cylinders with OPC-SDA binary blended cement for the three different calcination methods. Nine control concrete cylinders, with same dimension of 150mm x 300mm, using 100% OPC or 0% replacement with pozzolan were also produced. This gives a grand total of 90 concrete cylinders. All the concrete cylinders were cured in water by immersion. Three concrete cylinders from each of the three SDA calcination methods and for each of the three percentage replacement levels of OPC with pozzolan, as well as three control concrete cylinders were tested for saturated surface dry bulk density and crushed to obtain their split tensile strengths at 28, 90, and 150 days of curing.

Excel Spreadsheet Regression Analysis was used to develop the empirical models for predicting the split tensile strengths of OPC-SDA concrete for each of the three calcination methods. Relationship between the variables was established and the model was done in the standard linear-interactive manner according to Cindy and Robert (2007). A statistical adequacy test for the mathematical model was done using statistical Student's t-test at 95% accuracy level. The following two hypotheses were tested:

i. **Null Hypothesis:** There is no significant difference between the laboratory concrete cylinder split tensile strength results and predicted split tensile strength results from the model at 95% accuracy level.
ii. **Alternative Hypothesis:** There is significant difference between the laboratory concrete cylinder split tensile strength results and predicted split tensile strength results from the model at 95% accuracy level.

III. RESULTS AND DISCUSSION

The split tensile strength values are shown in Table 1 for the control concrete and for each of the three calcination methods (Open Air Calcination—OAC, Stove Calcination—SC, and Furnace Calcination—FC) and three % replacement levels (5%, 10%, and 15%) of the OPC-SDA binary blended cement concrete, as well as for each of the three days of curing (28, 90, and 150 days).

Table 1. Split tensile strengths of OPC-SDA blended cement concrete

% Replacement of OPC with SDA	Calcination Method	Split Tensile Strength (N/mm^2)		
		28days	90days	150days
0		0.88	1.34	1.61
5	OAC	0.78	1.10	1.51
	SC	0.75	1.29	1.70
	FC	0.90	1.41	1.87
10	OAC	0.43	0.76	1.39
	SC	0.35	1.08	1.66
	FC	0.60	1.36	1.77
15	OAC	0.60	0.65	1.34
	SC	0.42	0.80	1.41
	FC	0.43	0.97	1.54

It can be seen from Table 1 that the split tensile strength values of the OPC-SDA blended cement for OAC and SC methods at all three percentage replacement levels of OPC with SDA were lower than the control value at 28 days, but increased to become comparable to the control values at some later days of curing. Whereas the control value at 28 days of curing was 0.88N/mm^2, the greatest values for OAC and SC methods were 0.78N/mm^2 and 0.75N/mm^2 at 5% SDA replacement. The control split tensile strength value rose to 1.34N/mm^2 at 90 days and 1.61N/mm^2 at 150 days whereas the greatest 90 and 150-day split tensile strength values were 1.10N/mm^2 and 1.51N/mm^2 respectively for OAC method and 1.29N/mm^2 and 1.70N/mm^2 respectively for SC method. Table 1 also strikingly shows that the 28-day split tensile strength values of the OPC-SDA blended cement for FC method are comparable to the control values for 5% and 10% replacement of OPC with SDA and increase rapidly to exceed the control values at 90 and 150 days.

These results in general confirm the findings of earlier researchers that concrete containing agricultural by-product pozzolans have lower strength than the control concrete at earlier curing ages as a result of the low rate of pozzolanic reaction at those early ages (Hossain, 2003; Adesanya and Raheem, 2009a; Ettu et al., 2013e; Ettu et al., 2013f). The silica from the pozzolans reacts with calcium hydroxide liberated as a by-product during the hydration of OPC to form additional calcium-silicate-hydrate (C-S-H) that increases the binder efficiency and the corresponding strength values at later days of curing. Thus, the strength gain is both as a result of continued hydration of OPC and the increased pozzolanic reaction (Balendran and Martin-Buades, 2000; Ramasamy, 2012).

Table 1 further shows that among the three calcination methods, split tensile strength values for Furnace Calcination (FC) method are much greater than those for Open Air Calcination (OAC) and Stove Calcination (SC) methods for all the days of curing and all percentages of replacement of OPC with SDA. This is in agreement with the results of the chemical analysis of the ashes that showed the ash from FC method as good pozzolan which satisfied the ASTM requirement that the sum of SiO_2, Al_2O_3, and Fe_2O_3 should be not less than 70% for pozzolans. The higher grade of ash from FC method could be because the FC method is better controlled than the OAC and SC methods.

The models developed for FC, OAC, and SC methods are shown in Equations 1, 2, and 3 respectively, where Y represents tensile strength, X_1 represents curing age in days, and X_2 represents Percentage replacement of OPC with SDA.

$$Y = 0.65026 + 0.00816X_1 – 0.02080X_2 \quad 1$$
$$Y = 0.68142 + 0.00647X_1 – 0.03020X_2 \quad 2$$
$$Y = 0.59125 + 0.00815X_1 – 0.02833X_2 \quad 3$$

The result of t-test analysis showed that the null hypothesis is accepted and alternative hypothesis rejected. Hence, the models are adequate for predicting the split tensile strength values of OPC-SDA binary blended cement concrete at different curing ages and for 5-15% replacement of OPC with SDA, using SDA obtained from any of the three calcination methods investigated in this work.

IV. CONCLUSION

i. The split tensile strength of OPC-SDA concrete decreases as the percentage replacement of OPC with SDA increases.
ii. The split tensile strengths of OPC-SDA concrete using SDA obtained from Open Air Calcination and Stove Calcination methods are lower than the control concrete (100% OPC concrete) values at lower ages of hydration, but increase to become comparable to the control concrete values at 150 days.
iii. The 28-day split tensile strengths of OPC-SDA concrete using SDA obtained from Furnace Calcination method are comparable to the control values for 5% and 10% replacement of OPC with SDA and increase rapidly to exceed the control values at 90 and 150 days.
iv. The split tensile strength of OPC-SDA concrete with SDA obtained from Furnace calcination method have higher strength values than those with SDA obtained from Open air calcination and Stove calcination methods. Split tensile strength values from Open Air calcination method are not consistently greater or less than those from Stove calcination method.
v. Based on split tensile strength values, OPC-SDA blended cement concrete with SDA obtained from Furnace Calcination could be used for all building and civil engineering works at 5-10% OPC replacement with SDA where early loading of the structural members are not required.
vi. Also, based on split tensile strength values, OPC-SDA blended cement concrete with SDA obtained from Furnace Calcination at 15% OPC replacement with SDA and with SDA obtained from Open Air and Stove Calcination methods at 5-10% OPC replacement with SDA could be used for minor building and civil engineering works where high concrete strength and early loading of the structural members are not required.
vii. The models developed in this work could be used to predict the split tensile strength values of OPC-SDA binary blended cement concrete at 28-150 days of hydration, within 5-15% replacement of OPC with SDA, using SDA obtained from furnace calcination, open air calcination, or stove calcination methods.

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