Tensile Strengths of Concrete Containing Rice Husk Ash from Different Calcination Methods

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Abstract -*Rice Husk Ash (RHA) was produced using three different calcination methods namely: Open Air Calcination (OAC), Stove Calcination (SC), and Furnace Calcination (FC). OPC was partially replaced with RHA 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 RHA and for each of the three calcination methods, making a total of eighty one concrete cylinders with OPC-RHA binary blended cement. Nine control concrete cylinders, with same dimensions of 150mm x 300mm, were also produced using 100% OPC. The concrete cylinders were 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-RHA concrete. It was found that whereas the split tensile strength of the control concrete at 28 days of curing was 0.88N/mm², the greatest values of 0.87N/mm² (FC), 0.82N/mm² (FC), and 0.70N/mm² (OAC) were obtained at 5%, 10% and 15% RHA replacement. 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 split tensile strength values for the OPC-RHA concrete were 1.49N/mm² and 2.01N/mm². Among the three calcination methods, split tensile strength values for Furnace Calcination (FC) were highest, followed by values for Open Air Calcination (OAC), while values for Stove Calcination (SC) were generally lowest. OPC-RHA blended cement concrete could be used for all building and civil engineering works at 5-15% OPC replacement with RHA using RHA obtained from FC method, and at 5-10% OPC replacement with RHA using RHA obtained from OAC and SC methods, where early loading of the structural members are not required.*

Key Words:**Concrete, Ordinary Portland Cement, Split Tensile Strength, Rice Husk Ash, Furnace Calcination, Open Air Calcination, Partial replacement.**

1.INTRODUCTION

Researchers have continued to intensify efforts at sourcing local materials that could be used as partial replacement for Ordinary Portland Cement (OPC) in building and civil engineering works. 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 [1]. Portlandite (Calcium hydroxide [$Ca(OH)_2$]) 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 $Ca(OH)_2$ 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 $Ca(OH)_2$ and increase the quantity of the beneficial calcium-silicate-hydrate. Dwivedia et al. [2] 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 (FA) and silica fume (SF) are already widely used in many countries [3]. 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. Recent studies by [4], [5], and [6] have confirmed the suitability of Nigerian RHA and SDA as pozzolanic materials for producing concrete, sandcrete, or soilcrete. Reference [7] 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 increment in the strength of concrete. Reference [8] studied the effect of incorporating RHA in concrete on the hydration, microstructure and interfacial zone between the aggregate and paste. Based on the investigation, they concluded that: (i) The paste incorporating RHA had lower $Ca(OH)_2$ content than the control Portland cement paste; and (ii) Incorporation of RHA in concrete reduced the porosity in the interfacial zone; the width of the interfacial zone between the aggregate and the cement paste compared with the control Portland cement composite was also reduced.

Reference [9] studied the properties of ternary blended cementitious (TBC) systems containing OPC, ground Malaysian RHA, and fly ash(FA). 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. Reference [10] 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 carried by [11], [12], [13], [14], and [15] showed that the outstanding technical benefit of incorporating a cement replacement material in concrete is that it significantly improves the durability properties of concrete to various chemical attack due to its reduced permeability arising from a pore refining process. Reference [16] 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. References [17] and [18] 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.

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 [14].

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 [19, 20]. Reference [19] 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^{0}C if the combustion time is less than one hour, whereas crystalline silica is produced at 1000^{0}C with combustion time greater than 5minutes. Reference [20] showed that in muffle furnace 600^{0}C is the appropriate temperature for rice husk ash preparation with large specific surface area due to the existence of nanoscale and amorphous silica. Reference [21] 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. They also stated that RHA concrete gave excellent improvement in strength for 10% replacement.

Since the use of OPC-RHA blended cement concrete is becoming more and more acceptable, there arises a need to produce RHA using calcination processes easily adaptable to dwellers in rice growing communities in South Eastern Nigeria. Hence, this work investigated the tensile strengths of concrete containing RHA obtained from different calcination methods that could be replicated by local community dwellers.

2.METHODOLOGY

Rice husk was obtained from rice milling factories in Afikpo, Ebonyi State in South Eastern Nigeria. This material was air-dried and calcined into ashes using three different simple 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^{o}C and 600^{o}C. The stove combustion was done using improvised cylindrical stove commonly used by local dwellers at a temperature generally below 700^{o}C. The furnace burning was done using local pit crucible furnace fired with coke at a temperature of 600-800^{o}C. 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 RHA obtained from OAC had bulk density, specific gravity, and fineness modulus of 780kg/m^3, 1.86, and 1.48 respectively. Corresponding values for that obtained from SC were 760kg/m^3, 1.79, and 1.44 respectively, while values for that obtained from FC were 785kg/m^3, 1.82, and 1.50 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 localstone 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 rice husk ashes. It consists of mixing 20g of the ash with 100ml volume 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 they 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.

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 RHA 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 RHA 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 RHA and for each of the three calcination methods, making a total of eighty one concrete cylinders with OPC-RHA 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 RHA 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-RHA concrete for each of the three calcination methods. Relationship between the variables were established and the model was done in the standard linear-interactive manner according to [22]. 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.

3. 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-RHA binary blended cement concrete, as well as for each of the three days of curing (28, 90, and 150 days).

It can be seen from Table 1 that the split tensile strength values of the OPC-RHA blended cement for all the three calcination methods and at all three percentage replacement levels of OPC with RHA were lower than the control value at 28 days, but increased to become comparable to and even greater than 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 of 0.87N/mm^2 (FC), 0.82N/mm^2 (FC) and 0.70N/mm^2 (OAC) were obtained at 5%, 10% and 15% RHA replacement.

Table-1: Split Tensile Strengths of OPC-RHA Blended Cement Concrete

% OPC Replacement	Calcination Method	Split Tensile Strength in N/mm^2		
		28 days	90 days	150 days
0		0.88	1.34	1.61
5	OAC	0.86	1.42	1.85
	SC	0.82	1.31	1.71
	FC	0.87	1.49	2.01
10	OAC	0.78	1.37	1.74
	SC	0.72	1.25	1.64
	FC	0.82	1.44	1.89
15	OAC	0.70	1.25	1.59
	SC	0.57	1.28	1.52
	FC	0.65	1.30	1.66

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 for the OPC-RHA concrete were 1.49N/mm^2 and 2.01N/mm^2. These results confirm the findings of earlier researchers that concrete containing rice husk ash (RHA) 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 [23, 24, 25, 26]. The silica from the RHA 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 [27, 28].

Table 1 further shows that the 150 day split tensile strengths of OPC-RHA concrete at 5%, 10%, and 15% replacement of OPC with RHA are greater than the control concrete strengths for all the three calcination methods. Furthermore, among the three calcination methods, split tensile strength values for Furnace Calcination (FC) are highest, followed by values for Open Air Calcination (OAC), while values for Stove Calcination (SC) are generally lowest. This could be because the FC method is better controlled than the others, while the SC method does not have enough oxygen (air) for proper and full combustion of the rice husk particles.

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 RHA.

$$Y = 0.65023 + 0.00810X_1 - 0.00587X_2 \quad (1)$$

$$Y = 0.68378 + 0.00732X_1 - 0.00740X_2 \quad (2)$$

$$Y = 0.66162 + 0.00716X_1 - 0.01073X_2 \quad (3)$$

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

4. CONCLUSIONS AND RECOMMENDATIONS

i. The split tensile strength of RHA-OPC Concrete decreases as the percentage replacement of OPC with RHA increases.

ii. The split tensile strengths of RHA-OPC Concrete using RHA obtained from Furnace Calcination, Open Air Calcination, and Stove Calcination methods are lower than the control concrete (100% OPC concrete) value at lower ages of hydration, but increase to become comparable to and even greater than the control concrete values at higher hydration ages of 90 to 150 days.

iii. The split tensile strength of RHA-OPC concrete with RHA obtained from Furnace calcination method have higher strength values than those with RHA obtained from Open air calcination and Stove calcination methods. Split tensile strength values from Open Air calcination RHA are also higher than those from Stove calcination RHA.

iv. Based on split tensile strength values, OPC-RHA blended cement concrete with RHA obtained from Furnace Calcination could be used for all building and civil engineering works at 5-15% OPC replacement with RHA where early loading of the structural members are not required.

v. Also, based on split tensile strength values, OPC-RHA blended cement concrete with RHA obtained from Open Air and Stove Calcination methods could be used for all building and civil engineering works at 5-10% OPC replacement with RHA where early loading of the structural members are not required.

vi. The models developed in this work could be used to predict the split tensile strength values of OPC-RHA binary blended cement concrete at 28-150 days of hydration, within 5-15% replacement of OPC with RHA, using RHA obtained from furnace calcination, open air calcination, or stove calcination methods.

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