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Split Tensile Strengths of Concrete Incorporating Rice Husk Ash and SawDust Ash

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***Abstract*—This work investigated the split tensile strengths of concrete containing rice husk ash (RHA) and saw dust ash (SDA). RHA and SDA were obtained from open air calcination. Ordinary Portland cement (OPC) was partially replaced with each of RHA, SDA, and RHA-SDA at 5%, 10%, and 15%. Nine concrete cylinders of dimensions 150×300mm were produced using 100% OPC. Eighty one concrete cylinders also of dimensions 150×300mm were similarly produced for each of the percentage replacement of OPC with RHA, SDA, and RHA-SDA, making a total of 252 concrete cylinders. The concrete cylinders were cured by immersion and tested for split tensile strength at 28, 90, and 150 days. Models were developed to predict the tensile strengths of concrete containing RHA and SDA as binary and ternary blends with OPC at varying percentage replacements and curing ages. The split tensile strength decreased with increasing percentage replacements of OPC with RHA, SDA, and RHA-SDA. At 28 days of curing, values of 0.86N/mm^2, 0.78N/mm^2, and 0.70N/mm^2 were obtained at 5%, 10%, and 15% replacements of OPC with RHA respectively. Values of 0.77N/mm^2 and 0.58N/mm^2 were obtained at 5% and 10% replacements of OPC with SDA respectively. Values of 0.82N/mm^2 and 0.64N/mm^2 were obtained at 5% and 10% replacements of OPC with RHA-SDA respectively. Split tensile strengths of concrete with RHA, SDA, and RHA-SDA were lower at early age of curing but improved at later ages. For 5% replacement of OPC with RHA values of 1.42N/mm^2 and 1.85N/mm^2 were obtained at 90 and 150 days of curing respectively. For 5% replacement of OPC with SDA values of 1.28N/mm^2 and 1.65N/mm^2 were obtained at 90 and 150 days of curing respectively. For 5% replacement of OPC with RHA-SDA values of 1.35N/mm^2 and 1.66N/mm^2 were obtained at 90 and 150 days of curing respectively. Values for the control were 1.34N/mm^2 and 1.61N/mm^2 at 90 and 150 days of curing respectively. Thus, based on split tensile strength values, concrete produced with 5% to 15% replacement of OPC with RHA and 5% to 10% replacement of OPC with RHA-SDA could be used in reinforced and unreinforced concrete works where time of loading is not critical. The models developed were tested and found to be adequate for predicting split tensile strengths of binary and ternary blended OPC-RHA-SDA cement concretes.**

Keywords—Split Tensile Strength, Concrete, Ordinary Portland Cement, Pozzolana, Rice Husk Ash, Saw Dust Ash, Binary Blend, Ternary Blend

I. INTRODUCTION

Cementitious binders are used for many types of construction activities. Researchers have greatly intensified efforts at sourcing local materials that could be used as partial replacement for Ordinary Portland Cement (OPC) in 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]. Calcium hydroxide ($Ca(OH)_2$) is obtained as one of the hydration products of 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 $Ca(OH)_2$ and increase the quantity of the beneficial C-S-H. Reference [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, 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 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 [$Ca(OH)_2$] and calcium silicate hydrates (C-S-H) were the major hydration and reaction products in the RHA paste. Because of the pozzolanic reaction, 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 and the $Ca(OH)_2$ amount 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 as much as 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, 15] showed that the outstanding technical benefit of incorporating cement replacement materials is that it significantly improves the durability properties of concrete to various chemical attacks 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.

The strength of construction material is essential to engineers. 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 pavement slabs and airfield runways [14]. Tensile strength is also used in both serviceability and ultimate limit state calculations such as the evaluation of cracking moment for prestressed elements, the design of fibre-reinforced concrete, developing moment curvature diagrams, and the calculation of deflection of structural members.

Regression analysis can be used to estimate a function which predicts values of a response variable in terms of values of other independent variables. Reference [19] define regression analysis as a conceptually simple method for investigating functional relationships among variables. The relationship is expressed in the form of an equation or a model connecting the response or dependent variable and one or more explanatory or predictor variables, as shown in (1).

$$Y = Q(X1, X2 \dots \dots \dots \dots .. XK) \qquad (1)$$

Where Y is the dependent variable or the response and X_k are the independent variables or factors. The investigator also typically assesses the statistical significance of the estimated relationship between the independent variables and dependent variable, that is, the degree of confidence on how the true relationship is close to the estimated statistical relationship.

II. METHODOLOGY

Rice husk was obtained from rice milling factories in Amasiri, Ebonyi State while Saw dust was obtained from timber milling factories in Owerri, Imo State, all in South-Eastern Nigeria. These materials were air-dried and calcined into ashes by Open Air Calcination (OAC) using an open furnace. The open burning was done at an uncontrolled degree of temperature that ranged between 450^{o}C and 600^{o}C as measured with a type-k thermocouple. The ashes were 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 treatment to improve the quality of the ashes and enhance their pozzolanicity was applied because the researchers wanted to utilize simple processes that could be easily replicated by local community dwellers.

The RHA had bulk density, specific gravity and fineness modulus of 780kg/m^3, 1.92, and 1.48 respectively. The SDA had corresponding values of 750kg/m^3, 1.84, and 1.86 respectively. Other materials used for the 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 sandstone 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 ashes. It consists of mixing 20g of 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 pozzolan 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 RHA 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 SDA had the sum of SiO_2, Al_2O_3, and Fe_2O_3 as 50.03% which is less than 70% for pozzolans, but its loss on ignition was 7.59 which is less than 12 specified by ASTM.

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. RHA and SDA were each binary blended with OPC at 5%, 10%, and 15% replacement of OPC with the ashes. OPC was also replaced in a ternary blend by mixing RHA and SDA in a ratio of 70:30 for each of the percentage replacements. The ashes were 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 proportion. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity. Nine control concrete cylinders of 150mm x300mm were produced using 100% OPC or 0% replacement with pozzolan. Eighty one concrete cylinders were also produced for each of the percentage replacement of OPC with RHA, SDA, and RHA-SDA, making a total of 252 concrete cylinders. All the concrete cylinders were cured in water by immersion. Three concrete cylinders for each percentage replacement of OPC with pozzolan and the control were tested for saturated surface dry bulk density and crushed to obtain their split tensile strengths at 28, 90, and 150 days of curing.

Empirical models were developed using Excel Spreadsheet Regression Analysis. The model for the tensile strength estimation was done in the standard linear-interactive manner according to [20]. Relationship between various variables were established. 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 strengths and predicted split tensile strength results at 95% accuracy level.

ii. Alternative Hypothesis: There is a significant difference between the laboratory concrete cylinder split tensile strengths and predicted split tensile strength results at 95% accuracy level.

III. RESULTS AND DISCUSSION

The particle size distribution analysis showed that the RHA and SDA were much coarser than OPC, the reason being that the ashes were not ground to finer particles. Therefore, the split tensile strength values obtained using them could still be improved upon when the ashes are ground to finer particles. The pozzolanicity test confirmed the ashes as pozzolans since they fixed some quantities of lime $[Ca(OH)_2]$ over time. The split tensile strengths of the OPC-RHA and OPC-SDA binary blended cement concrete, as well as that of OPC-RHA-SDA ternary blended cement concrete are shown in Table 1 for 28, 90, and 150 days of curing.

Table 1 indicates that split tensile strength generally increases with curing age and decreases with increased amount of the pozzolanic ashes. The result at 28 days showed a decrease in strength from 0.88N/mm^2 for the control to 0.70N/mm^2, 0.62N/mm^2, and 0.50N/mm^2 for 15% replacement of OPC with RHA, SDA, and RHA-SDA respectively. These results indicate that concrete containing rice husk ash (RHA) and sawdust ash (SDA) have low strengths at early curing age. This could be as a result of the low rate of pozzolanic reaction at those early ages as noted by previous researchers [21, 22, 23, 24, 25].

The results at 90 days show that the split tensile strength values for 5% and 10% binary blended OPC-RHA concrete and 5% ternary blended OPC-RHA-SDA concrete were higher than the control values, with up to 8% increases in strength. 10% replacement of OPC with RHA-SDA gave a strength comparable with the control value. Split tensile strength values of the blended cement concretes were even higher at 150 days than the control value. This is most likely because of increased pozzolanic reaction whereby the silica from the pozzolans reacts with calcium hydroxide liberated as a by-product of 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.

Table 1. Split tensile strengths of OPC-RHA, OPC-SDA, and OPC-RHA-SDA cement concrete

% OPC Replacement	Blend type	Split Tensile Strength in N/mm^2		
		28 days	90 days	150 days
0	*OPC*	*0.88*	*1.34*	*1.61*
5	*OPC-RHA*	*0.86*	*1.42*	*1.85*
	OPC-SDA	*0.77*	*1.28*	*1.65*
	OPC-RHA-SDA	*0.82*	*1.35*	*1.66*
10	*OPC-RHA*	*0.78*	*1.37*	*1.74*
	OPC-SDA	*0.58*	*1.15*	*1.50*
	OPC-RHA-SDA	*0.64*	*1.33*	*1.69*
15	*OPC-RHA*	*0.70*	*1.25*	*1.59*
	OPC-SDA	*0.62*	*0.97*	*1.47*
	OPC-RHA-SDA	*0.50*	*1.18*	*1.49*

Maximum split tensile strength values of 1.85N/mm^2, 1.66N/mm^2, and 1.65N/mm^2 at 150 days were obtained for concrete with 5% replacement of OPC with RHA, RHA-SDA, and SDA respectively. Maximum values of 1.74N/mm^2, 1.69N/mm^2, and 1.50N/mm^2 at 150 days were obtained for concrete with 10% replacement of OPC with RHA, RHA-SDA, and SDA respectively. Similarly, maximum values of 1.59N/mm^2, 1.49N/mm^2 and 1.47N/mm^2 at 150 days were obtained for concrete with 15% replacement of OPC with RHA, RHA-SDA, and SDA respectively.

The models developed are shown in (2), (3), and (4) for OPC-RHA binary blended concrete, OPC-SDA binary blended concrete, and OPC-RHA-SDA ternary blended concrete respectively. Y represents split tensile strength, X_1 represents curing age in days, and X_2 represents percentage replacement of OPC with RHA, or SDA, or RHA-SDA.

$$Y = 0.68378 + 0.007323X_1 - 0.0074X_2 \quad (2)$$

$$Y = 0.61579 + 0.00693X_1 - 0.01853X_2 \quad (3)$$

$$Y = 0.653102 + 0.007409X_1 - 0.01433X_2 \quad (4)$$

T-test analysis showed that the null hypothesis is accepted while the alternative hypothesis is rejected. In other words, there is no significant difference between the laboratory concrete cylinder split tensile strength and model predicted split tensile strength results at 95% accuracy level. Therefore, the developed models are adequate.

IV. CONCLUSIONS AND RECOMMENDATIONS

i. RHA-OPC binary blended concrete and RHA-SDA-OPC ternary blended concrete have higher split tensile strengths than SDA-OPC binary blended concrete.

ii. The split tensile strength values of RHA-OPC, SDA-OPC and RHA-SDA-OPC blended concretes generally decrease with increase in percentage replacement of OPC with the pozollanic ashes and increase with the curing age.

iii. The split tensile strength values of RHA-OPC and RHA-SDA-OPC blended concretes are lower than the control values at 28 days of curing but increase to become greater than the control values at 90 and 150 days of curing.

iv. Tensile strength models for two component RHA-OPC concrete, two component SDA-OPC concrete and three component RHA-SDA-OPC concrete was developed, tested, and found to be adequate.

v. Based on split tensile strength values, concrete produced with 5% to 15% replacement of OPC with RHA and 5% to 10% replacement of OPC with RHA-SDA could be used in general reinforced and unreinforced concrete works where early strength is not a critical factor.

vi. Concrete produced with 5% to 15% replacement of OPC with SDA and 15% replacement of OPC with RHA-SDA could be used for minor concrete works where strength is of less importance.

vii. The developed split tensile strength models could be used by engineers to predict the strengths of RHA-OPC and SDA-OPC binary blended concrete, as well as RHA-SDA-OPC ternary blended concrete.

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