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Compressive Strength and Thermal Properties of Concrete Incorporating Coconut Shell Ash as Cement Replacement

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ABSTRACT

Coconut shell is an agricultural waste residue obtained from de-husking of coconut. This study investigated the compressive strength and thermal properties of concrete made by partially replacing (0, 5, 10, 15, 20, 25) Portland Limestone Cement with Coconut Shell Ash (CSA). Coconut shell was calcinated at 600^{o}C, grinded and made to pass 75 micron sieve before it was tested for chemical analysis using x-ray fluorescence analyzer. A total of 120 (150 x 150 x 150 m^3) grade 25 concrete cube specimens were cast using 0.65 water-cement ratio. The specimens were then cured and tested for compressive strength, thermal conductivity, volumetric heat capacity and thermal resistivity at 7, 14, 21 and 28 days respectively. Result of the chemical composition of CSA showed that it is a good pozzolan with combined SiO_2, Al_2O_3 and Fe_2O_3 of 76.4%. The slump and compacting factor were observed to decrease as the percentage of CSA increase. The compressive strength decreased with increase in CSA replacement. The 5 and 10% replacement of CSA had 28 day compressive strength values of 26.20 and 24.10 N/mm^2 respectively as against control value of 27.82 N/mm^2. The thermal conductivity, volumetric heat capacity decreased steadily while thermal resistivity increased. The thermal conductivity for both air dried and oven dried samples decreased from 1.2 w/mk to 1.01 w/mk as against the control value of 1.35 w/mk and 1.42 w/mk to 1.00 w/mk as against the control value of 1.55 w/mk respectively. As CSA content increases from 5 to 25%, a similar trend was observed for volumetric heat capacity but thermal resistivity increased from 85.950 c.cw/w to 108.2/0c.cw/w as against the control 85.110c.cw/w for both air and oven dried. Regression models for compressive strength revealed that there is close agreement between the experimented and predicted values with coefficient of regression R= 0.99. It is concluded that CSA exhibit better insulating properties and can be used up to 10% for in plain concrete construction.

1. INTRODUCTION

Concrete is a very good construction materials made by mixing cement, coarse aggregate (granite), sharp sand, soft sand, and water either in designed or prescribed proportions. The overall cost of concrete production largely depend on the availability and cost of its constituent materials. The rising cost of building materials, environmental concerns and sustainability issues has led to investigations into the use of agricultural residues as pozzolan in concrete production. Pozzolanas are siliceous and aluminous material which ordinarily have little or no cementitous properties but in finely divided form and in the presence of moisture can react with calcium hydroxide that liberated during the hydration of ordinary Portland cement to form compounds possessing cementitous properties (ASTM C618, 2005). Tijani *et al.* (2018a) showed that the use of chip agricultural waste is more appropriate to reduce the overall cost of concrete and reduce the quantity of cement used in concrete production. This in turn led to reduction in environmental pollution associated with cement production. It also assures economic and environmental benefits along with providing a way of disposing agricultural waste product with little alternative use.

Due to hike in the cost of building construction most especially cement as the binder, the need to evaluate the alternative binder (cement) materials should be our uttermost concerned. The cost of cement used in concrete work is on the increase and unaffordable, yet needs for housing and other construction work cannot be overlooked. Researchers like Tijani *et al*. (2020), Olawale and Tijani (2019), Olawale *et al.* (2018), Tijani *et al*. (2018b), have worked on possible ways to reduce the cost of cement in construction industries and at the same time to maintain the quality, strength, and workability of pozzolanic materials derived from an agricultural wastes. Mehta and Monteiro (2001) assessed microstructure, properties and temperature of concrete containing bamboo leave ash. Raheem and Adesanya (2011) investigated the thermal conductivity of corn cob ash blended with cement mortar. Oladunjoye (2012) presented a study on thermal diffusivity, thermal resistivity and specific heat capacity of soil. They concluded that concrete do not attain their thermal properties at 28 days and the thermal insulation coconut shell ash in concrete are dependent on its pozzolanic activities.

In this study, the compressive strength and thermal properties (thermal conductivity, resistivity and volumetric heat capacity) of concrete made by partially replacing (0, 5, 10, 15, 20, 25) Portland Limestone Cement with Coconut Shell Ash (CSA) were investigated. This is to ensure sustainability in construction and produce concrete that exhibit better insulating properties.

2. METHODOLOGY

The coconut shell used for the experiment were collected from Apata, Ibadan, Oyo-state, Nigeria. They were burnt in an open burner with limited supply of air at temperature 600°C. The obtained ash (CSA) was grinded after cooling and allowed to pass through sieve size No 75mm. The sample was tested at West Africa Portland Cement Company (WAPCO) Sagamu, Ogun State, Nigeria, for physical and chemical analysis using x-ray fluorescent analyzer (model QX 1279). The cement used was Dangote product, gotten from a local retailer in Ibadan. Sharp sand used was free from impurities and the granite used was 12mm maximum size, both aggregates were obtained from local quarries in Ibadan. The sand was obtained from Sasa sand quarry and has specific gravity, 2.68, bulk density, 1530, water absorption, 1.80 and fineness modulus 4.00 according to Ajagbe *et al.* (2017, 2018) while the coarse aggregate used was obtained from Express quarry and has specific gravity, 2.81, bulk density, 1530, water absorption, 0.67, fineness modulus 2.01 and aggregate crushing value, 19.70 according to Ajagbe *et al*. (2015, 2018)

Coconut shell ash were incorporated to replace cement partially at 0 to 25% (with 5% at interval). The samples produced with no CSA incorporated into the concrete mixes represented control experiment. The mix ratio 1:2:4 was adopted with water cement ratio of 0.65. Table 1 shows mix proportion of CSA concrete used. Slump and compacting factor tests were carried out on concrete in fresh state in accordance to the requirement of BS 1881: Part 102 and 103 respectively. A total of 120 (150 x 150 x 150 m^3) grade 25 concrete cube specimens were cast. The specimens were then cured and tested for compressive strength, thermal conductivity, volumetric heat capacity and thermal resistivity at 7, 14, 21 and 28 days respectively.

The concrete compressive strength was determined using crushing machine with strength calibration of 1500 kN (model 50 – (34 AC). The strength of compressed concrete was on the average of the three cubes. The concrete cubes with pin like holes were tested for thermal conductivity, resistivity and volumetric heat capacity at the ages 7, 14, 21 and 28 days, using KD2 pro thermal properties analyzer.

Table 1: Mixed proportion for CSA concrete

% replacement of CSA	Weight of cement	Weight of CSA	Weight of Fine aggregates	Weight of Coarse Aggregate	Weight of water	Water cement ratio
0	13.89	0	27.72	55.54	8.33	0.65
5	13.20	1.69	27.72	55.54	8.33	0.65
10	12.50	1.39	27.72	55.54	8.33	0.65
15	11.81	2.08	27.72	55.54	8.33	0.65
20	11.11	2.78	27.72	55.54	8.33	0.65
25	10.41	3.49	27.72	55.54	8.33	0.65

3. RESULTS AND DISCUSSIONS

Chemical Analysis of CSA

Table 2 shows the result of chemical constituents of CSA. The major chemical composition of CSA was silica content (SiO_2) having the percentage composition of 35.89%. According to BS EN 197-1:2000 the reactive silicon dioxide content in a good pozzolan should not be less than 25.0% by mass. The results indicated that the sum of percentages of silica, alumina, and iron oxide was 76.4% which is greater than 70% specified by ASTM C 618 (2005). The coconut shell ash has lower silica percentage of (35.89%) than that of sorghum husk ash with a percentage of 55.30% (Tijani *et al.*, 2019)

Table 2: Chemical composition of Coconut Shell Ash (CSA)

	Percentage Composition (%)			
Chemical Constituents	Sample 1	Sample 2	Sample 3	Average
SiIO2	35.62	37.16	34.89	35.89
Al2O3	26.31	24.41	23.24	24.65
Fe2O3	14.71	16.97	15.89	15.86
CaO	3.62	4.76	5.06	4.48
MgO	2.06	1.76	1.46	1.76
SO3	0.86	0.62	0.97	0.82
Na2O	1.01	0.86	0.91	0.92
K2O	0.74	0.86	0.99	0.84
CaCO3	4.32	3.62	2.99	3.64
LOI	10.82	11.01	10.14	10.66
Total SiO_2+Al_2O_3+Fe_2O_3	76.64	78.54	78.02	76.4%

Slump and Compacting Factor

The results of the slump and compacting factor, indicating the workability of the CSA concrete are shown in Figures 1 and 2. The figures indicated that the slump value decreases as the percentage of CSA increases. The compacting factor also decreased as the CSA percentage is increased. From the results, it can be deduced that concrete became less workable as the CSA percentage increases meaning that more water is required to make the mixes more workable. The high demand for water as CSA increase is due to greater proportion of silica. This is in line with previous finding of Wang and Baxter (2009).

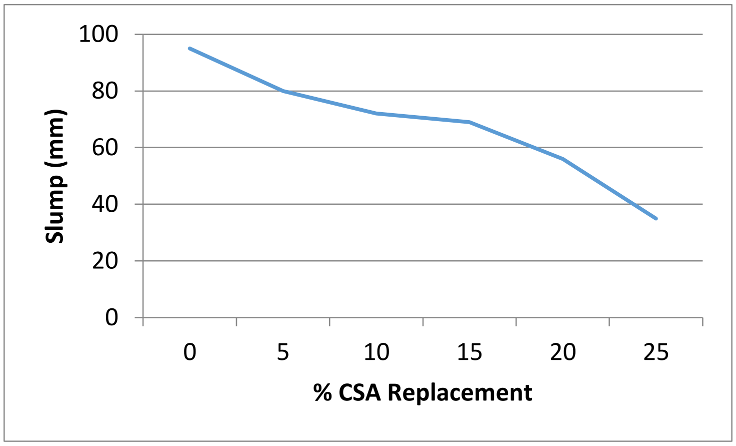

Figure 1: Slump of CSA Concrete

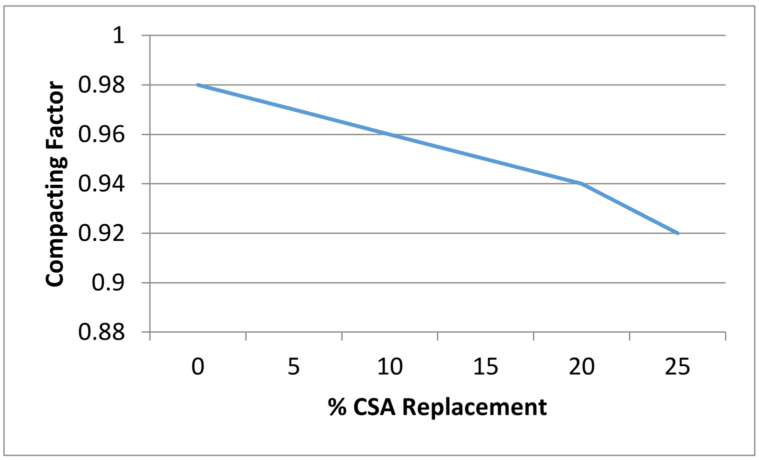

Figure 2: Compacting Factor of CSA

Compressive Strength

The results of the compressive strength test at 7, 14, 21 and 28 days is shown in Figure 3. As anticipated, an increase in compressive strength with increase in curing age from 7 to 28 days was observed. However, there is an observed steady decrease in compressive strength from 0 to 25% SHA replacement. The 28 days compressive strength which is the measure of strength of concrete is of utmost interest in this study. The highest strength of 27.82 N/mm^2 was obtained at 28 days for the control. The compressive strength of the 5% CSA at 28 days was obtained to be 26.20 N/mm^2 while that of 10% CSA was 24.10 N/mm^2. The compressive strength of 15, 20 and 25% were less than 20 N/mm^2. The reason for the reduction in strength could be due to mixing effect of cement and formation of weaker C-S-H gel as a result of pozzolanic reaction of CSA. Mosley *et al.* (2007) reported that concrete with minimum cube strength of 20N/mm^2 is recommended for use in plain concrete construction. However, higher concrete cube strength such as 30, 37 and 45 N/mm^2 is recommended to be used for reinforced concrete foundations and other reinforced concrete structural members (BS EN 1992- 1-1, 2004).

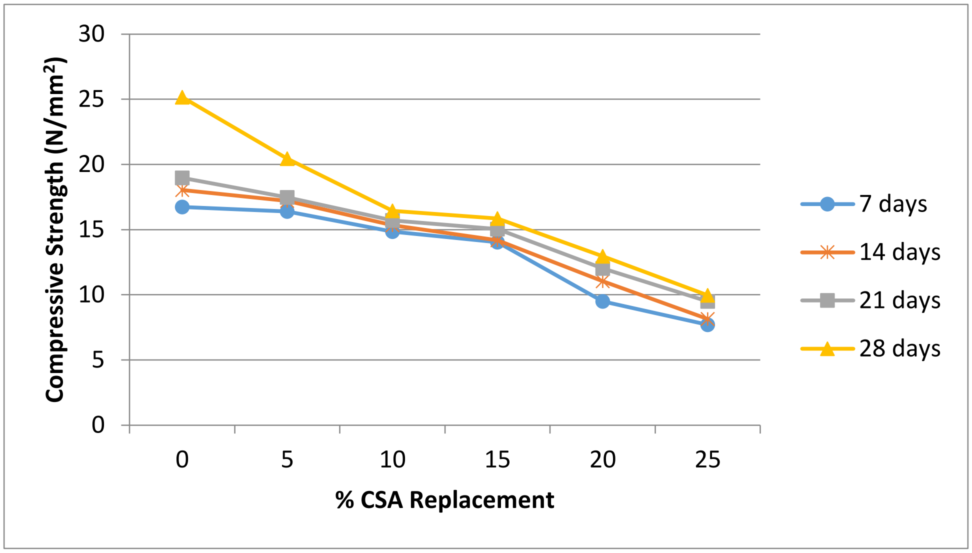

Figure 5: Compressive strength of CSA Concrete

Thermal Properties

The results of thermal properties when air and oven dried are presented in Tables 3 to 8. The Tables presented the effects of CSA percentage replacement on the thermal properties of concretes (thermal resistivity, volumetric heat capacity and thermal conductivity) when air dried and oven dried. It was observed from the tables that the thermal conductivity when air drying increase from 1.10 w/mk to 1.52w/mk. It increased in all classes with increase in curing age but decreased as the percentage replacement of CSA increases. The thermal conductivity when oven dried follows the same trend as when air dried but there was abrupt increase in the value compared to when air dried. The thermal resistivity when air drying increases as the percentage replacement of CSA increases and with curing age is increase. But the thermal resistivity when oven drying increases as the percentage replacement of CSA increases but decreases as the curing age increases. The volumetric heat capacity of CSA concrete when oven drying increases as curing age is increased and decreases as the percentage of CSA increased. The results presented in the tables are in line with previous findings of Amana *et al.* (2014) and Mijinyawa *et al.* (2015). The value of volumetric heat capacity after oven dried reduces compared to air drying due to decrease in moisture content. The concrete replacement at 25% of CSA of 7 days has highest value of thermal resistivity and it is therefore recommended to building as it will improve insulation properties. This is in cognizance to the previous findings of Raheem and Adesanya (2011).

Table 3: Result of thermal conductivity of Coconut Shell Ash cement concrete when air drying

Coconut Shell Ash replacement (%)	Avrg. Temp. (^{0}C)	Moisture content (%)	Thermal Conductivity W/mk			
			7 day	14 day	21 day	28 day
0			1.10	1.35	1.41	1.52
5			1.10	1.24	1.50	1.78
10	24.8	3.92	1.06	1.19	1.21	1.49
15			1.01	1.10	1.16	1.39
20			0.98	1.01	1.06	1.60
25			0.91	0.99	1.01	1.31

Table 4: Result of thermal resistivity of Coconut Shell Ash cement concrete when air drying

Coconut Shell Ash replacement (%)	Avrg. Temp. (^{0}C)	Moisture content (%)	Thermal Resistivity (^{0}C.cm/w)			
			7 day	14 day	21 day	28 day
0			80.80	84.22	84.92	83.01
5			82.14	85.98	86.91	87.62
10	24.8	3.92	85.11	90.81	91.51	90.06
15			92.16	93.61	94.91	96.92
20			101.21	101.28	103.04	103.92
25			109.62	108.21	111.04	111.61

Table 5: Result of volumetric heat capacity of Coconut Shell Ash cement concrete when air drying

Coconut Shell Ash replacement (%)	Avrg. Temp. (^{0}C)	Moisture content (%)	Volumetric Heat capacity (MJ/m^{3}k)			
			7 day	14 day	21 day	28 day
0			3.42	3.78	3.89	4.65
5			3.16	3.67	3.83	4.16
10	24.8	3.92	2.98	3.41	3.53	3.92
15			2.57	3.11	3.29	3.67
20			2.38	3.03	3.08	3.33
25			2.19	2.68	2.79	3.29

Table 6: Result of thermal conductivity of Coconut Shell Ash cement when oven drying

Coconut Shell Ash replacement (%)	Avrg. Temp. (^{0}C)	Moisture content (%)	Thermal Conductivity (W/mk)			
			7 day	14 day	21 day	28 day
0			1.36	1.56	1.61	1.79
5			1.38	1.44	1.61	1.74
10	34.5	3.10	1.37	1.38	1.51	1.64
15			1.10	1.33	1.37	1.51
20			1.03	1.19	1.29	1.32
25			0.99	1.08	1.18	1.24

Table 7: Result of thermal resistivity of Coconut Shell Ash cement when oven drying

Coconut Shell Ash replacement (%)	Avrg. Temp. (^{0}C)	Moisture content (%)	Thermal Resistivity (^{0}C.cm/w)			
			7 day	14 day	21 day	28 day
0			93.11	91.10	84.16	81.96
5			95.16	94.20	89.16	86.11
10			98.98	96.69	89.91	89.01
15	34.5	3.10	103.98	104.11	96.69	97.98
20			110.62	109.39	102.78	101.68
25			113.79	111.89	104.86	103.62

Table 8: Result of volumetric heat capacity of Coconut Shell Ash cement concrete when oven drying

Coconut Shell Ash replacement (%)	Temp. (^0C)	Moisture content (%)	Volumetric Heat capacity (MJ/m^3k)			
			7 day	14 day	21 day	28 day
0			3.31	3.42	3.57	4.16
5			3.18	3.31	3.30	3.71
10	34.5	3.10	2.82	2.98	3.03	3.06
15			2.71	2.71	2.81	3.01
20			2.49	2.55	2.65	2.76
25			2.24	2.35	2.41	2.45

Regression Equations for Compressive Strength and Thermal Properties of CSA Concrete

Table 9 presents the regression equations for compressive strength and thermal properties of CSA concrete. The Microsoft Excel office package (Office 2013) was used to generate the regression equations. It was observed that the experimental values and the predicted values are in close agreement. The result regression equations had very high coefficient of correlations, 0.971 for compressive strength, 0.990 for thermal conductivity, 0.899 for volumetric heat capacity and 0.981 for thermal resistivity.

Table 9: Regression equations for compressive strength and thermal properties

	Curing Age	Regression Equation	Computed value	Experimented value
Compressive Strength	28	$y=0.009x^2-0.964x+25.21$ $R^2=0.971$	25.21	25.15
Thermal conductivity	28	$y=0.019x^2-1.096+1.76$ $R^2=0.990$	1.91	1.79
Volumetric heat capacity	28	$y=0.014x^2-1.34x+4.65$ $R^2=0.899$	4.71	4.65
Thermal resistivity	28	$y=0.0041x^2-0.6673x+110.14$ $R^2=0.981$	112.06	111.61

4. CONCLUSION

The following conclusions were drawn from the study:

i. Coconut Shell Ash is a suitable material for use as a good pozzolan since it satisfies the requirement of 76.4% by having the percentage sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ greater than 70%.

ii. The compressive strength of concrete reduced as the percentage of Coconut Shell Ash content increased. However, CSA can be used up to 10% for in plain concrete construction

iii. There exist a high potential for the use of Coconut Shell Ash as a better insulating properties than normal Portland cement concrete.

iv. The selected models R^2 (0.899-0.990) were adequate for compressive strength and thermal properties predictions

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