Hygrothermal Effects of Partial Replacement of Coarse Aggregates with Palm Kernel Shell in Concrete Production

A. Abdullahi, M. Abubakar, H. O. Aminulai, A. Yusuf, B. Alhaji
Civil Engineering Department, Federal University of Technology, Minna, Nigeria
Email: Katchali20@yahoo.com

Abstract
Hygrothermal effects of partial replacement of coarse aggregates with Palm Kernel Shell (PKS) in concrete production were assessed. Preliminary tests were conducted on PKS to determine its suitability for use as aggregate in concrete production. Workability and Density of the fresh concrete were also determined. Cylinders of 100mm diameter by 50mm height were used to cast the concrete; these were cured for 28 days and tested for water absorption and sorptivity at different replacement levels of coarse aggregates with PKS. The sorptivity of concrete was found to increase with increase in PKS content, however, between 5-25% PKS content, lower sorptivity values than control were recorded. Water absorption of concrete also increased with increase in PKS content, PKS contents from 5-20% gave water absorptions below the control and at 25% replacement, a slightly higher value as compared to the control was recorded. From the results obtained, concrete with 5% PKS content was found to possess the best water absorption as well as sorptivity values. Such concrete adequately fits for use in areas where concrete water absorption and sorptivity are required to be kept at a very minimal level; such as in the construction of drainages and dams.
Key words: Hygrothermal, Coarse aggregates, Sorptivity, Water absorption, Palm kernel shell (PKS).

Introduction

The necessity to provide decent accommodation for citizens around the world has thrown up two very important needs; namely, a reduced cost of providing these accommodations and an increased quality of such buildings. As Concrete continues to be the construction material of choice for many around the world, the costs of its conventional constituents (i.e. cement, crushed stones and sand) have been on a steady rise and hence, the overall cost of construction has risen. This has posed a great deal of challenge to the construction industry and the quality discharge of a great number of developmental projects suffers, (Anthony, 2000). In line with this, (Shetty, 2005) affirmed that the prices of concrete elements primarily depend on the cost of material and labour. With material cost accounting for two thirds of the entire project costs, (Neville, 2010) and aggregates (coarse and fine) making up 70-80% of the total concrete volume, (Falade, et'al., 2010), a substitute and cheaper aggregate material will go a long way in reducing the overall cost of buildings and ultimately, housing deficits. As a result, it has become imperative to emphasize the development and use of locally available construction materials in the construction of functional but low-cost buildings in both rural and urban areas (Owolabi, 2012). Also, the use of agricultural wastes such as coconut shell, PKS, saw dust and their likes will improve the sanitary condition of the environment from which they have been removed, (Abdullahi, et'al,.2013, Bala, et'al,.2013)

Palm Kernel Shell (PKS) has been known to have the potential to be used in concrete works on a large scale as early as the 1990s and early 2000s, (Mohammad, 2007). Beyond 2000, research into utilization of Palm Kernel Shell as light weight concrete and other uses along with its accompanying advantages of reduced dead weight, thermal insulation e. t. c., had received a big boost, (Chandra and Berntsson, 2002),. It was discovered that PKS has an approximate compressive strength of 18N/mm² (Zarina, et'al., 2016). In using this concrete as external elements, especially in tropical humid climates, there is an increasing need to apply retrofitting measures to it; this is to guard against moisture penetration in the form of rain water, dammed water as well as water passing through drainage canals through the wall barriers (Oyekan and kamiyo, 2011). To control these movements, a wide variety of procedures and materials have been employed; namely, experimental solutions and numerical simulations. However, the experiments are time consuming, expensive and often problematic. The mathematical modelling on the other hand, still grapples with insufficient data on material properties and transport coefficients to be able to adequately evaluate real thermal and moisture transfer processes, as a result, a great deal of investigatory work still needs to be done (Andreas, et' al., 2010). There are several tests for hygrothermal properties, these include: thermal conductivity, sorptivity, suction isotherm, vapour permeability, liquid diffusivity, water absorption and air permeability. For the purpose of this research, sorptivity and water absorption are considered as they would add to the bank of data required to overcome some of the challenges enumerated above.

Materials and Method

Materials

Perm Kernel Shell (PKS)

PKS having a grading size of between 9.0-13mm was used as partial replacement of coarse aggregates at 5, 10, 15, 20 and 25% of the total coarse aggregate value. This was obtained from dump sites around Minna metropolis, headquarters of Chanchaga local government area, Niger State, Nigeria, where they exist in abundance. The PKS used was thoroughly washed, air-dried and bagged.

Cement

Ordinary Portland cement (OPC) of 42.5R grade of the Dangote brand was used. This was found to conform to the specifications of OPC as required by BS 12 (1996).

Aggregates

Fine and Coarse aggregates were used for this research. Locally available river sand passing through the 5mm BS test sieve, and having a specific gravity of 2.66 served as the fine aggregates. Crushed granite stone aggregates of 10mm to 15mm nominal size and having a specific gravity of 2.69 served as coarse aggregates. Both aggregates conformed to the standard set by BS 882 and are therefore suitable for concrete production.

Water

The source of water was bore holes drilled on the campus of Federal University of Technology, Minna, which was pumped to the laboratory from overhead tanks. The water was found to be potable and clean. It therefore satisfies the required specification for making concrete as described in BS 3148 and is therefore suitable for concrete production (BSI, 1980).

Methods

The concrete cylinders were cast according to BS 1811. Workability of concrete was assessed using Slump. Density of concrete was determined according to BS EN 12390-7.

The coarse aggregate replacement with PKS was varied from 0-25%, in steps of 5.

Six (6) concrete cylinders were cast for each percentage replacement to give a total of thirty six (36) concrete cylinders in all. These cylinders measured 100mm diameter by 50mm height. The cylinder moulds were oil-smeared on the inside to avoid sticking to the concrete and to allow for easy demoulding. Preliminary tests were conducted on the constituent concrete materials to establish their adequacy for concrete production. Table 1 shows the required quantities of materials needed for the experiment in line with the adopted mix design ratio of 1:2:4 and a water/cement ratio of 0.65.

The constituent materials were thoroughly mixed until a uniform and consistent mixture was obtained in all cases. Vibration to remove entrapped voids was done manually using a tamping rod and the concrete specimens were left in the mould for 24 hours. They were then demoulded and cured in water for 28 days.

Water Absorption Test

The $100mm$ diameter by $50mm$ height concrete cylinders after curing for 28 days, were oven-dried for 24 hours at a constant temperature of 110℃ until the mass became constant as revealed by taking the mass readings repeatedly. This mass was noted as the dry mass (W_1) of the cylinder. After that, the concrete cylinder was immersed in water for 4 hours. The mass of concrete cylinder was then recorded as wet mass (W_2). The difference in mass as a percentage of the original mass gives the water absorption of the cylinder cube.

Water absorption$=\frac{W_2-W_1}{W_1} X\ 100\%$

Where: W_1 = mass of oven dried concrete cylinder, in grams,

W_2= mass of concrete cylinder after immersing in water, in grams.

Sorptivity Test

Sorptivity test, which measures the ability of a material to absorb and transmit water by capillarity, was carried out as follows. Dry masses of the concrete cylinders (W_1) were taken as described in 2.2.1. The concrete cylinders were then placed in an open container with water level not rising beyond $5mm$ from the base. The flow from the peripheral surface was prevented by sealing it off properly with a non-absorbent coating (nylon bag). The quantity of water absorbed in a period of 30 minutes was measured by weighing the specimen on a weighing balance as(W_3). Surface water on the specimen was wiped off with a dry tissue paper.

The mathematical relation given by (Pitroda and Umrigar, 2013) that the cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t), was used to calculate the sorptivity

$$I = S.t^{1/2} \quad (2)$$

Where:

S= sorptivity in ($\text{gmm}^{-2}\text{min}^{1/2}$)

t = elapsed time in minutes.

$$I = \frac{\Delta W}{AD} \quad (3)$$

Where,

ΔW = change in mass = W_3-W_1

W_1 = oven dry mass of cylinder, in grams

W_3 = mass of cylinder after 30 minutes capillary suction of water in grams.

A= surface area of the specimen through which water penetrated.
D = density of water

Table1: Proportion of Concrete Constituents

% of PKS	Mix Ratio	W/C Ratio	Cement mass (Kg)	Water mass (Kg)	Sand mass (Kg)	Gravel mass (Kg)	PKS mass (Kg)
0%	1:2:4	0.65	0.53	0.35	1.06	2.13	
5%	1:2:4	0.65	0.53	0.35	1.06	2.02	0.11
10%	1:2:4	0.65	0.53	0.35	1.06	1.91	0.21
15%	1:2:4	0.65	0.53	0.35	1.06	1.81	0.32
20%	1:2:4	0.65	0.53	0.35	1.06	1.70	0.43
25%	1:2:4	0.65	0.53	0.35	1/06	1.59	0.53
Total			3.18		6.38	11.16	1.6

Plate 1: Setup for Sorptivity Test

Plate 2: Setup for weighing Balance

Results and Discussions

Preliminary tests carried out on constituent concrete materials are presented in **Table 2**. PKS shows a water absorption rate of 22.58%, which is close to the value of 25.64% recorded by (Zarina, et'al., 2016). The difference in water absorption may be attributable to the differences in species and methods of preparing the PKS samples. Fine and coarse aggregates used for the experiment had 1.0 and 0.45% water absorptions respectively. These fall well within the range of less than 2% specified by (Neville, 2010).The specific gravity of PKS was found to be 1.20. This falls within the range of 1.03 by (Owolabi, 2012) and 1.21 by Zarina et al, 2016). Specific gravity for both fine and coarse aggregates were found to be 2.66 and 2.69, falling within 2.6 to 2.7 range given by (Neville, 2010), with even the allowance for slightly higher or lower values.The compacted average result of bulk density for PKS was found to be 566.67kg/ m^3 which falls within the range of 500–900kg/ m^3 for "pumice aggregates" as given by (Neville, 2010). A maximum size of 19.5mm coarse aggregates was used.

The density and slump of fresh concrete were also determined and results are jointly presented in Table 3. From the density results obtained, 0-25% replacement of coarse aggregate with PKS, produce light weight concrete as they fall below the average density of normal concrete which is 2400kg/ m^3 (Zarina etal, 2016). Slump results showed a linear decline from 119mm at control to 100mm at 25% replacement of coarse aggregate with PKS, indicating that workability of concrete increased as PKS content increased.

Table 2 Results of Preliminary Analysis of Aggregates

Test	Water absorption (%)	Maximum size (mm)	Specific gravity (Gs)	Bulk density (kg/ m^3)
Materials				
PKS	22.58	13.0	1.20	566.67
Fine aggregate	1.0	5.0	2.66	1787.2
Coarse aggregate	0.45	19.5	2.69	1436

Table 3: Density and Slump of Concrete

% Replacement of Coarse aggregate with PKS	Density of Concrete (kg/m^3)	Concrete Slump (mm)
0	2001.4	120
5	1997.3	118
10	1983.6	111
15	1976.5	108
20	1970.4	103
25	1957.3	100

Water Absorption

Three samples from each percentage replacement of coarse aggregate were used and the averages, taken. The results are presented in Table 4. At control, a 7.55% water absorption was recorded which is greater than water absorption values for 5%, 10%, 15% and 20% replacements. However, 25% replacement showed slightly higher water absorption than the control. The reduction in water absorption between 0% and 5% replacement is due to obstruction of natural pore lines through which concrete absorbs water, at this stage, the interruption effect outweighs water absorption by PKS. However, as more PKS is introduced into the mix, the water absorption increases and hence the trend shown in the result. The absorption results from 0-25% replacements as shown in Table 4, all fall within the acceptable limit specified by(Neville, 2010) which limits water absorption to a range of 9-33%. This concrete behaviour is the same as the one investigated by (Zarina, et'al., 2016). This behaviour is expected as the PKS contains zero moisture, a function on which the water absorption depends, as reported by (Bala and Aminulai, 2014).

Table 4: Water Absorption of Concrete

% Replacement of Coarse aggregate with PKS	Mass of dry sample W_1 (g)	Mass of wet sample W_2 (g)	Water Absorption %
0	1020.9	1098.5	7.55
5	998.3	1056.5	5.89
10	992.2	1054.1	6.26
15	982.1	1044.2	6.32
20	974.0	1045.1	7.30
25	972.0	1046.5	7.67

Sorptivity

Sorptivity results for different percentage replacements are presented in Table 5. The values of sorptivity from 5% to 25% replacement of coarse aggregates with PKS fall below the value of control. Results show that the rates of absorption and transmission of water through capillary suction in concrete, increase as percentage replacement increases, water redistribution was found to be linear with the root of suction time while redistribution behaviour deviates from the √t, in line with the findings of (Andreas, et' al., 2010). From the results, the lower the sorptivity of concrete, the higher its resistance to water transportation in concrete and vice versa. This is because water transportation mainly depends upon the pore distribution and the micro structural properties of concrete.

Table 5: Sorptivity of Concrete

% Replacement of Coarse aggregate with PKS	Mass of dry sample W_1 (g)	Mass of wet sample W_3 (g)	Sorptivity ($gmm^{-2}/min^{½}$)
0	977.9	1000.8	0.53
5	988.2	1000.3	0.28
10	1032.5	1045.3	0.30
15	923.6	939.6	0.37
20	970.6	989.1	0.43
25	936.9	957.5	0.49

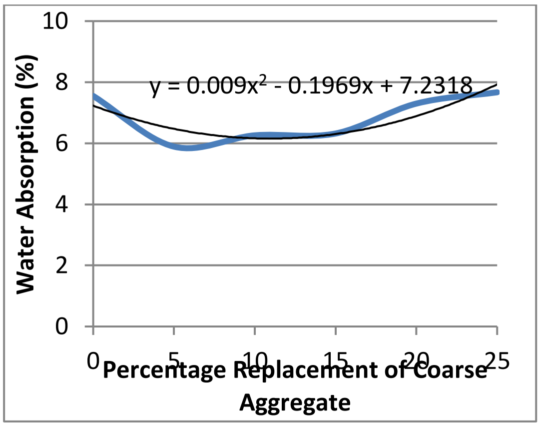

Figure 1: Plot of water Absorption against Percentage Replecement of Coarse aggregate with PKS

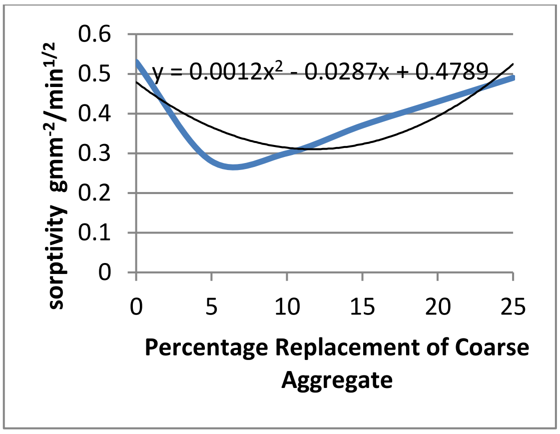

Figure 2: Plot of Sorptivity against Percentage Replacement of Coarse aggregate with PKS

Conclusion

After experimental investigation on the hygrothermal effects of partial replacement of coarse aggregate with 0 through 25% PKS, in steps of 5, in concrete production, the following can be concluded:

PKS has higher water absorption than crushed granite stones. However, the absorption at 5% through 20% PKS content in concrete is still less than the control absorption as shown in Figure 1. Furthermore, with the trend of water absorption exhibited by such concrete as the percentage replacement increases, water absorption will continue to increase. In this wise, the higher the PKS content in concrete, the higher its water absorption.

Percentage replacements of coarse aggregate with PKS from 5% through 25% give a sorptivity that keeps water transmission at a lower level than at control as shown in Figure 2, with 5% replacement giving the least sorptivity; Thus, sorptivity of concrete increases with increase in its PKS content. These properties can be positively utilised in areas where concrete water absorption and sorptivity are required to be kept at a very minimal level; examples of these include using such in the construction of drainages, dams and other similar structures.

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