INVESTIGATING THERMAL PROPERTIES OF SAWDUST ASH – CEMENT CONCRETE AS A POTENTIAL CONSTRUCTION MATERIAL

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ABSTRACT
This study examined the thermal properties of concrete produced from partial replacement of the cement content with Sawdust Ash (SDA). Sawdust collected from sawmill was burnt into ashes and analyzed for chemical composition (silica, alumina and iron oxide) using x-ray fluorescence analyzer. Concretes were produced by replacing 5 - 25% by weight of the cement with SDA. Slump and compacting factor tests were also carried out. A total of 72 concrete cubes (150 mm) were cast. Thermal conductivity (k), diffusivity (α) and specific heat capacity (C_P) of the cubes were determined at the ages of 7, 28, 56 and 90 days, using KD2 Pro thermal properties analyzer. The data obtained were analyzed with SPSS…. The percentages of silica, alumina and iron oxide obtained for SDA were 65.29%, 6.43% and 3.83%, respectively. The slump and compacting factor values ranged from 85 - 110 mm and 0.91 - 0.95 mm, respectively. k of the SDA concrete at 90 days at both room and elevated temperature decreased from 1.67 - 1.21 W/mK and 1.63 - 1.19 W/m^{3}K, respectively. Values of α at room and elevated temperature increased from 0.36 - 0.49 mm^2/s and 0.37 - 0.54 mm^2/s, respectively while the C_p at both room and elevated temperatures decreased from 3.79 - 2.63 MJ/m^{3}K and 3.19 - 2.18 MJ/m^{3}K, respectively. Second order polynomial equation described the relationship between the thermal properties and curing age. Thermal diffusivity increased with temperature. SDA exhibits good insulating properties required for external walls, partition walls of building and farm structures.

Keywords: Sawdust ash, Pozzolan, Workability, Thermal conductivity, Thermal diffusivity, Thermal resistivity, Specific heat capacity.

INTRODUCTION

The rising cost of building materials, environmental concerns and sustainability issues have led to investigations into the use of agricultural residues in concrete production. High cost of building materials, especially cement, has led many Nigerians into cutting corners in building construction works which often led to eventual failure of such buildings. Engineering consideration for the use of readily available but cheap and environmentally friendly alternative materials for concrete production is thus imperative. Researchers have identified some alternative materials among which are fly ash, slag, limestone-powder, siliceous materials and sawdust ash (Malik *et al.*, 2015). In addition to these, Fernandez (2007) reported some local alternative materials such as palm kernel shell, pulverized fuel ash, coconut shells among others which are produced from milling stations, thermal power stations, waste treatment plants and so on. Sawdust has been used from time to time for making light weight concrete (Marthong, 2012). Concrete is a very good construction material made by mixing cement, coarse aggregate (gravel or crushed stone), fine aggregate (Sand) and water either in designed or prescribed proportions. It is strong in compression and has offered some level of resistance to some chemical like sulphates. It also offers resistance to biological attack like termites. Steel, which is strong in tension, is sometimes incorporated in it, thus becoming "reinforced concrete" a strong and durable material, which can be formed into various sizes and shapes. This account for its wide spread use in civil engineering structures such as buildings and in dams construction (Smith and Smith, 1998). It also finds application in farm structures such as crop storage structures (silos), farm animal buildings, crop processing buildings etc. However, as a result of the daily increase in the cost of concrete material most especially cement, it becomes imperative to search for alternative available local material. Besides, when used in the construction of habitable building for man, farm animals or for storage purposes, temperature become a major factor for consideration in order to meet the comfort of the occupants of such buildings and enhancement of the shelf life of the crop stored therein. Omobowale *et al* (2015) highlighted the importance and influence of the thermal properties of materials of construction for storage structures on crop shelf life. Sawdust is abundantly available everywhere in the country but there are currently scanty publications on the thermal properties of sawdust ash in the literature. Thus, the objective of this research was to determine the thermal properties of sawdust ash (SDA) as partial replacement for cement in concrete production since it is available in large quantity in Nigeria and constituting environmental nuisance.

Materials and Methods

The sawdust used for this research work was collected from a sawmill at Irewole area of Saki, Oyo State, Nigeria. The sawdust was carefully collected to avoid mixing with sand. The sawdust came mainly from Mahogany, Obeche, Mansonia and black Afara, species of timber which are common in Nigerian markets. The collected sawdust was burnt into ashes by open burning in a metal container. The ash was sieved using 75 µm sieve after cooling to obtain ash that was fine enough to react perfectly with Ordinary Portland Cement (Elephant Brand). The granite used for this study was 12mm maximum size while the sharp sand used was free from impurities. Analysis of SDA for the determination of its pozzolanicity was carried out using X-Ray fluorescence Analyzer at the Central Control Room (CCR) of West African Portland Cement Company (WAPCO) Sagamu, Ogun state, Nigeria. Slump and compacting factor tests were carried out to check the effect of SDA on the workability of fresh concrete in accordance with the requirements of BS1881 (1983) for slump test and compacting factor tests.

Production of Concrete Cubes

The mixing involved the replacement of 5, 10, 15, 20 and 25% by the weight of Ordinary Portland Cement with sawdust ash. Concrete without sawdust ash served as control. The mix ratio used was 1:2:4 (cement, sand and granite) with water: cement ratio of 0.55. Cubic specimens with size 150 mm were cast for determination of thermal conductivity, thermal diffusivity and specific heat capacity. For each batch of SDA replacement, a total of twelve cubes were cast, totaling 72 cubes in all. They were subsequently placed in the curing tank covered with water for certain number of days prior to the thermal properties tests.

Determination of thermal properties

Thermal conductivity, volumetric specific heat capacity and diffusivity tests were carried out at room temperature with the KD2 Pro Thermal Analyzer (Decagon Device) in the Department of Agricultural Engineering laboratory, Ladoke Akintola University of Technology, Ogbomoso, Nigeria, after curing the cube specimens in a water tank for 7, 28, 56 and 90 days and air dried for 24hours. The experiment was repeated after the temperature of the cubes was raised by leaving them for 24hours in an oven operated at 120^{O}C. This was done in order to study the thermal behaviour of the concrete at different temperatures. Amana *et al.* (2014) described in detail the principles and procedures for determining thermal properties of materials using the KD2 Pro.

Results and Discussions

The temperatures of the samples obtained at room temperature ranged between 23.9 and 27.5 with a mean value of 25.7^{o}C. Corresponding values obtained at elevated temperatures (after heating for 24 hours) ranged 31.4 ^{O}C and 34.9 ^{O}C with an average of 33.15^{O}C.

Chemical composition of SDA

Table 1 shows the elemental oxide composition of sawdust ash samples. The result showed that SDA has combined percentages of ($SiO_{2+}Al_2O_{3+}Fe_2O_3$) of 75.55% which is more than 70% indicating that SDA is a good pozzolanic material in accordance with the requirements of ASTM C618 (2008). This is in line with the findings of (Elinwa and Ejeh, 2004; Raheem *et al.*, 2012). The SDA falls under the category of Class F pozzolan. The mean percentage Loss of Ignition of SDA was 4.23% which is below 6.00% maximum specified by ASTM C 618 [2008] for Class F pozzolans. The specific gravity of SDA was 2.05; compared to that of cement which is 3.15 indicating that SDA is lighter in weight than cement.

Table 1: Chemical Composition of Sawdust Ash

Chemical Constituents	Percentage composition (%)			
	Sample 1	Sample 2	Sample 3	Average
SiO_2	64.32	65.05	66.51	65.29
Al_2O_3	7.31	6.10	5.89	6.43
Fe_2O_3	3.62	4.06	3.80	3.83
CaO	10.25	11.05	11.53	10.94
MgO	1.73	2.33	2.05	2.04
SO_3	1.10	1.20	1.01	1.10
Na_2O	0.38	0.47	0.36	0.40
K_2O	2.36	2.54	2.22	2.37
$Caco_3$	7.88	8.50	7.39	7.92
LOI	4.06	4.66	3.98	4.23
LSF	1.96	1.10	2.03	1.70
SR	11.04	10.44	10.60	10.69
AR	12.67	11.75	12.77	12.46
$SiO_2+Al_2O_3+Fe_2O_3$	75.25	75.21	76.20	75.55

Sieve analysis of aggregates

The results of the sieve analysis for fine and coarse aggregates are presented in Figures 1 and 2 respectively. Figure 1 indicates that coefficient of uniformity (C_u) and coefficient of curvature (C_c) for fine aggregates are 5.30 and 1.32 respectively. Similarly, the C_u and C_c for coarse aggregates are 1.75 and 0.89 respectively (Figure 2). This shows that the aggregates are well graded (Raheem *et al.,* 2012). The specific gravity obtained was 2.05.

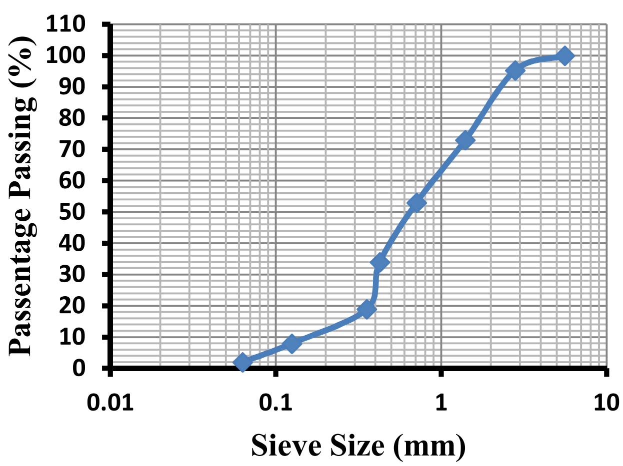

Figure 1: Grading curve of sharp sand

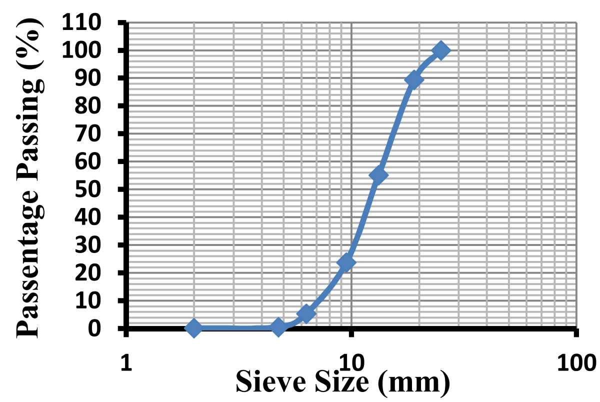

Figure 2: Grading curve of granite

Workability

The results of the slump test and compacting factors carried out are shown in Table 2 and 3 respectively. Table 2 indicates that the slump value decreased from 110 to 85 as the percentages of SDA increases from 0% to 25%. Similarly, Table 3 indicates that the compacting factor value reduced from 0.95 to 0.91 as the percentage of SDA increased from 0% to 25%**.** These results showed that the concrete becomes less workable as the percentage of SDA increases meaning that more water is required to make the mix more workable; since the mix was becoming stiff. The high demand for water as SDA increases is due to increased amount of silica in the mixture. This is the behavior of pozzolan cement concrete in which the silica-lime reaction would require more water in addition to the water needed during hydration of cement (Adesanya and Raheem, 2009).

Table 2: Slump of SDA Cement Concrete

% SDA	Slump (mm)
0	110
5	105
10	100
15	95
20	90
25	85

M **Table 3: Compacting Factor of SDA Cement Concrete**

% SDA	**Mass of cylinder + partially compacted concrete (kg)**	**Mass of cylinder + fully compacted concrete (kg)**	**Compacting factor**
0	17.40	18.30	0.95
5	16.90	18.00	0.94
10	16.85	18.10	0.93
15	16.60	17.80	0.93
20	16.60	17.82	0.93
25	16.30	17.90	0.91

Thermal Properties

Thermal conductivity of SDA concrete

The results of thermal conductivity (k) of SDA concrete at room temperatures ranged from 1.48 – 1.67 W/mk for control samples at room temperature to 1.44 – 1.63 W/mk at elevated temperatures whereas it ranged between 1.50 – 1.03 W/mk for 5- 25% SDA replacement at room temperature. Corresponding values at elevated temperatures ranged between 1.42 – 0.92 for 5 – 25% SDA replacement translating to a reduction in the thermal conductivity of control samples (pure concrete) by 36.1% after 25% SDA replacement. Figure 3 indicates that thermal conductivity of SDA concrete at room temperature generally increased with curing age and decreased with increase in percentage of SDA replacement. The results at day 7 showed a steady decrease in thermal conductivity from 1.48 W/mK for the control samples to 1.03 W/mK with 25% SDA replacement. This is a better result compared to the reduction in k from 1.816 to 1.283 W/mk reported by Amana *et al*. (2014) for 25% rubber replacement in concrete and Wimonsomg *et al*. (2012) for thermal conductivity of sawdust/polycarbonate composite. This reduction in thermal conductivity could be attributed to the presence of SDA in the concrete as the thermal property of composite material like concrete is dependent on that of its constituents (Wadso *et al*., 2012). The thermal conductivity of the control samples, however, increased from 1.48 at day 7 to 1.67 W/mK at 90 days. A similar trend was also observed at all levels of SDA replacement (Figure 3) but the effect of the increase was dampened by increase in percentage sawdust replacement such that a thermal conductivity of 1.21 W/mK was finally obtained after 90 days of curing with 25 percent SDA replacement. Thus long curing time, though required for the strength of the SDA, it seems to adversely affect k of the SDA with respect to thermal comfort in the building envelope both for human habitation and for crop storage and other agricultural purposes.

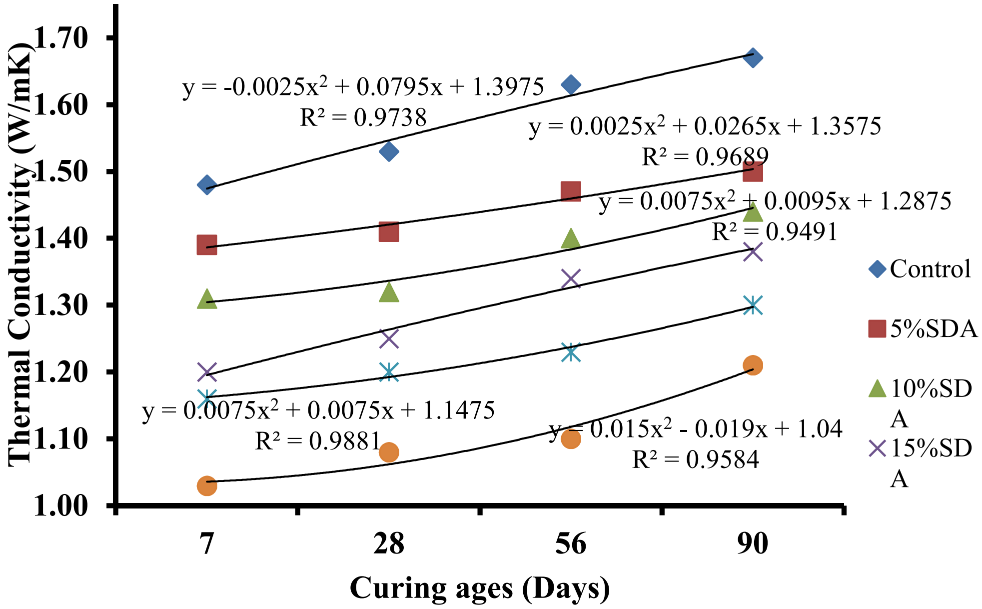

Figure 3: Thermal conductivity of SDA concrete at room temperature

Corresponding values obtained for k at elevated temperature generally followed the same trend as that obtained for room temperature (Figure 4) and were generally lower than those obtained at room temperature which eventually resulted into a final k value of 1.19 (W/mK) at 25% SDA replacement after 90 day of curing (Tables 4) thereby suggesting that k reduces with increase in temperature. The reduction in k at elevated temperature may be due to the reduction in the amount of moisture available in the SDA concrete due to the evaporative effect of the heat applied in raising the temperature. This suggests that the SDA could serve as a better alternative construction material in the tropics where the search for cheap but strong construction materials exhibiting poor thermal conductivity, especially for the purpose of storage and preservation of agricultural materials is on the increase. This is so because the environmental conditions in the tropics make storage of agricultural crop in concrete and metal silos a night mare as they exhibit higher thermal conductivity which makes the high ambient day temperature to be rapidly conducted through the walls of the silos to the stored produce consequently leading to spoilage. The SDA concrete with lower k, especially at elevated temperatures, when used for silos construction would protect against this occurrence especially during day when the ambient temperature is raised by the on-set of the sun. Results of the analysis of variance (ANOVA) of the thermal conductivity of SDA concrete showed that the independent factor (i.e. SDA content and curing age), when considered individually and jointly had significant effects on the thermal conductivity of the concrete at 95% confidence level. The relationship between thermal conductivity and curing time is best described by a second order polynomial equation as this gave higher coefficients of determination (R^2) ranging between 0.9491 and 0.9881 for room temperature and 0.9861 and 1 at elevated temperatures

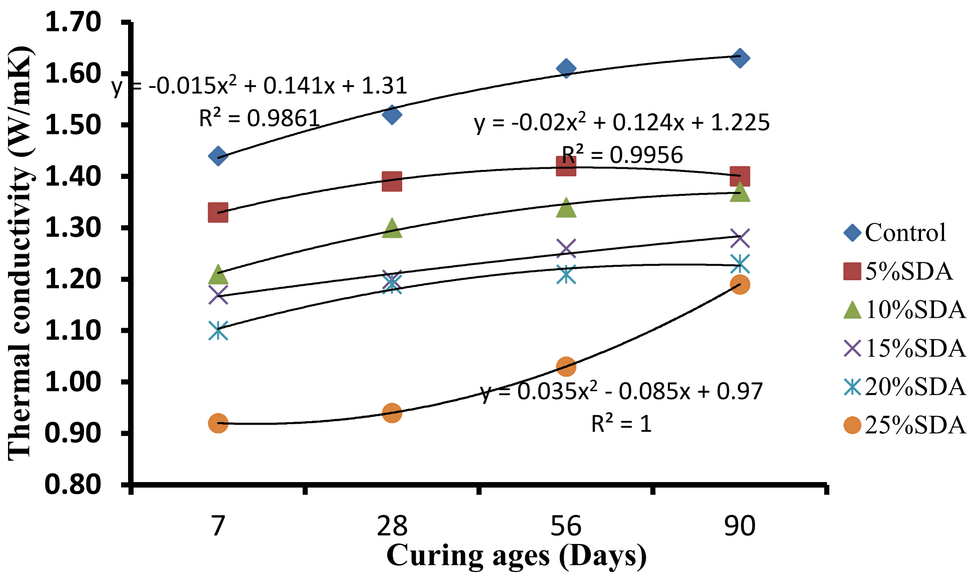

Figure 4: Thermal conductivity of SDA concrete at elevated temperature

Specific heat capacity of SDA concrete

Results of specific heat capacity of SDA concrete at room temperature ranged from 3.37 – 3.79MJ/m^{3}k for control to 3.19 – 3.46MJ/m^{3}k at elevated temperatures whereas it ranged between 2.29 – 3.30 MJ/m^{3}k at room temperature and 2.18 – 3.21 MJ/m^{3}k at elevated temperatures at 5 – 25% SDA replacement. Figure 5 indicates that specific heat capacity of SDA concrete at room temperature, just like thermal conductivity, generally increased non-linearly with curing age and decreased with SDA replacement. The results at day 7 showed a steady decrease in specific heat capacity from 3.37 MJ/m^{3}K for control to 2.29 MJ/m^{3}K with 25% SDA replacement. However, it increased from 3.37 at day 7 to 3.79MJ/m^{3}K at 90 days. This trend was also observed between 5 and 25% SDA replacement. This, however, decreased steadily to 2.63 MJ/m^{3}K after 25% SDA replacement after 90days curing period. The reduction in specific heat capacity with increased in SDA replacement could be attributed to the presence of SDA in the concrete used. This is in line with previous findings of Amana *et al,* (2014) for thermal performance of rubber concrete and Oladunjoye and Sanuade (2012) for specific heat capacity of soils. For a good thermal performance a building material is desired to have high specific heat capacity such that it shields the building envelope away from the impacts of changes in ambient temperature. Thus, decline in the values of specific heat capacity of the concrete with increased SDA replacement, though minimal, is a limitation. The specific heat capacity of the SDA concrete also increased with increase in curing age, the effect of increase was truncated by increase in sawdust ash percentage replacement such that a specific heat capacity of 2.63 MJ/m^{3}K was finally obtained at 90 days of curing at 25 percent SDA replacement. This was lower than the 3.37 MJ/m^{3}K recorded for control on the 7 days curing age. Despite the increase in specific heat capacity with curing age; the SDA is still a better material in terms of its specific heat capacity.

Similarly, the values obtained for specific heat capacity at elevated temperature generally followed the same trend as that obtained for room temperature (Figure 6) but the values were lower than those obtained at room temperature. The decreased in specific heat capacity at elevated temperature is evidently due to the loss of moisture as a result of heating. A further reduction in the specific heat at elevated temperature as recorded here is undesirable as any change in ambient temperature would be easily felt within the building envelope. Results of the analysis of variance showed that the independent factor (i.e. SDA content and curing age), when considered individually and jointly had significant effects on the volumetric specific heat capacity of the concrete at 95% confidence level. This indicates that whenever any of the factors varies, the volumetric specific heat capacity of the concrete changes and the degree of the variation is proportional to the magnitude of the change. The relationship between specific heat and curing time is best described by a second order polynomial equation as this gave higher coefficients of determination (R^2) ranging between 0.9513 and 0.9979 for room temperature and 0.9583 and 0.9983 at elevated temperatures

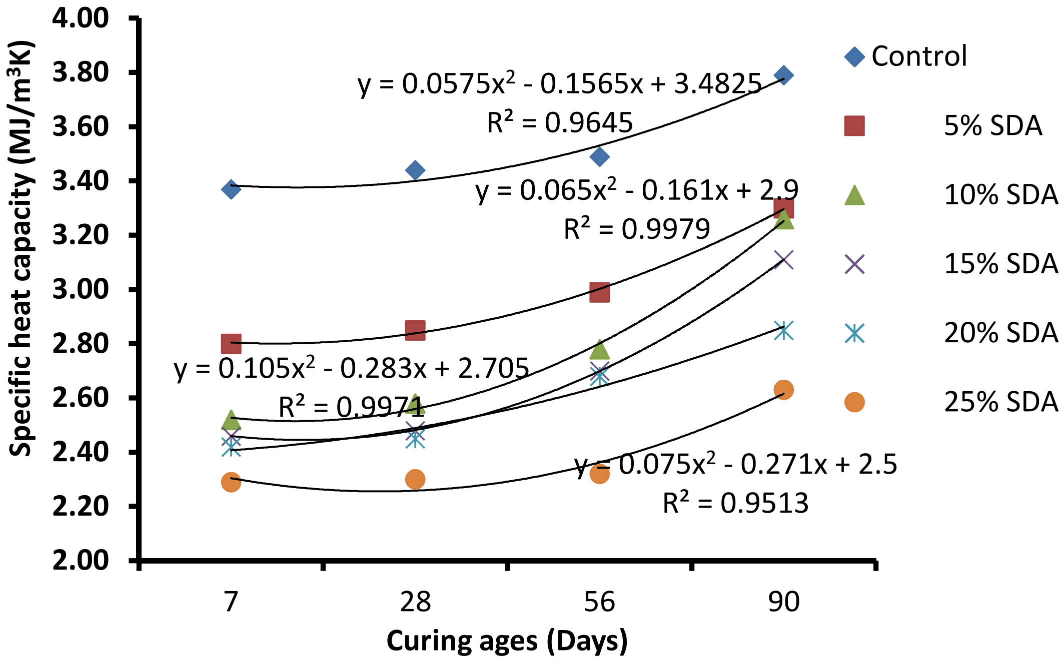

Figure 5: Specific heat capacity of SDA concrete at room temperature

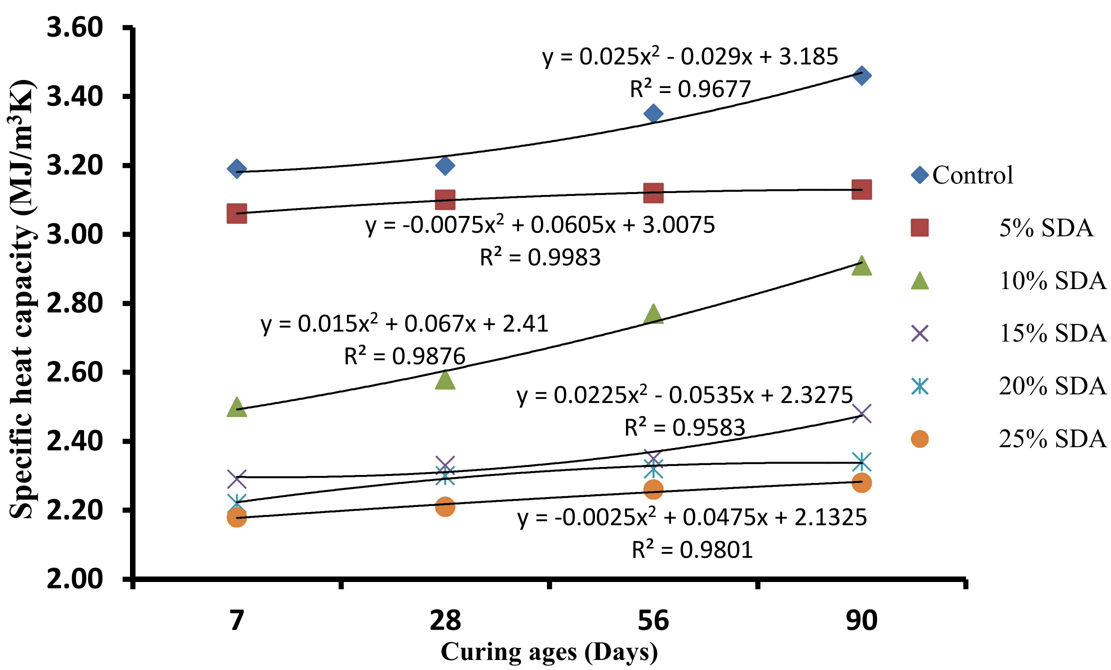

Figure 6: Specific heat capacity of SDA concrete at elevated temperature

Thermal diffusivity of SDA concrete

Results of thermal diffusivity of SDA concrete at room temperatures ranged from 0.40 – 0.49 m^2/s from 7 to 90 days of curing for control samples and 0.47 – 0.54 m^2/s at elevated temperatures whereas it ranged from 0.29 – 0.46 at room temperature to 0.30 – 0.52 at elevated temperatures with 5 – 25% SDA replacement. The thermal diffusivity was, however, observed to decrease as the percentage SDA replacement increased irrespective of the curing age (Figure 7). This shows that thermal diffusivity of SDA concrete at room temperature generally increased with curing age but decrease with increase in percentage SDA replacement as observed for both k and α. The results at 7 days, as presented in Figure 7, shows a steady decrease in thermal diffusivity from 0.40 mm^2/s for control (0% replacement) to 0.29 mm^2/s for 25% SDA replacement. However, it increased, for control, from 0.40 mm^2/s at day 7 to 0.49 mm^2/s at 90 days curing. The reduction in thermal diffusivity could be attributed to presence of SDA in the concrete used. This is in line with previous findings of Amana *et al.* (2014) for thermal performance of rubber concrete and the values were close to those obtained in this study especially at 25% SDA replacement. The increased in thermal diffusivity with increase in curing age means that the rate of heat transmission through the SDA concrete materials by the process of diffusion increased with curing age but reduced with increase in SDA percentage replacement such that a thermal diffusivity of 0.36 m^2/s was finally obtained at 90 days of curing at 25 percent SDA replacement. This was lower than the 0.40 m^2/s recorded for control on the 7th day of curing which indicates that the speed of change in temperature from one point to another within an SDA material when exposed to thermal variations would increase with curing age but decrease with percentage SDA replacement. A decrease in thermal diffusivity of concrete at day 7 by 37.9% with 25% SDA content indicates a decline in the ability of the concrete to undergo a temperature change when exposed to a fluctuating thermal environment. This is a desirable parameter for a building material to be qualified for consideration for human comfort and crop storage purposes.

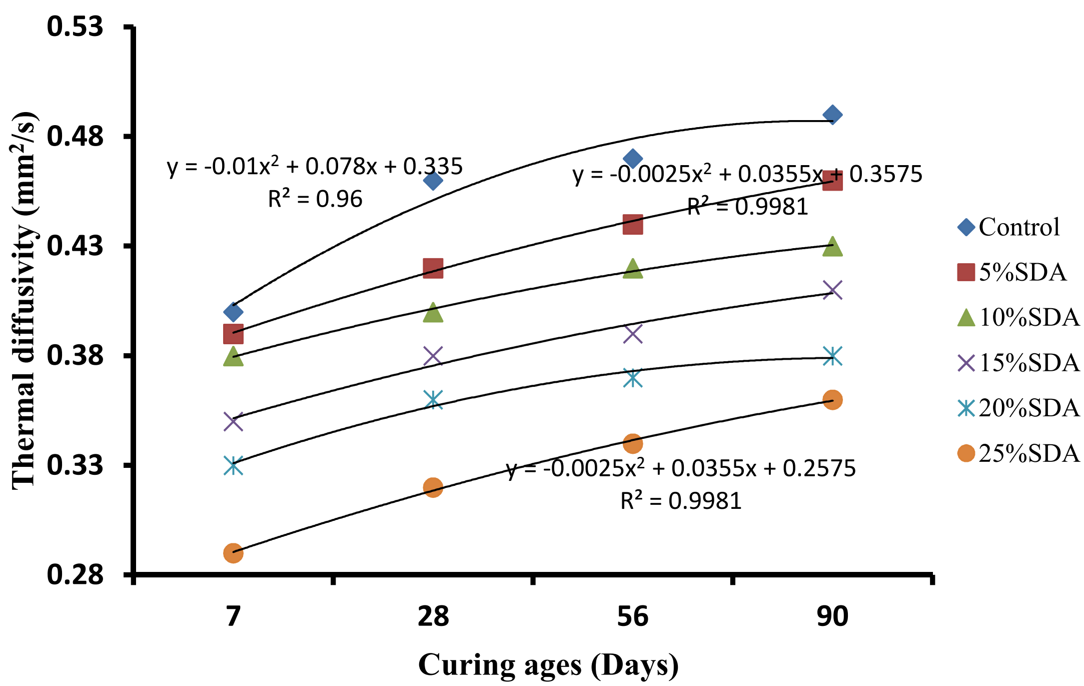

Figure 7: Thermal diffusivity of SDA concrete at room temperature

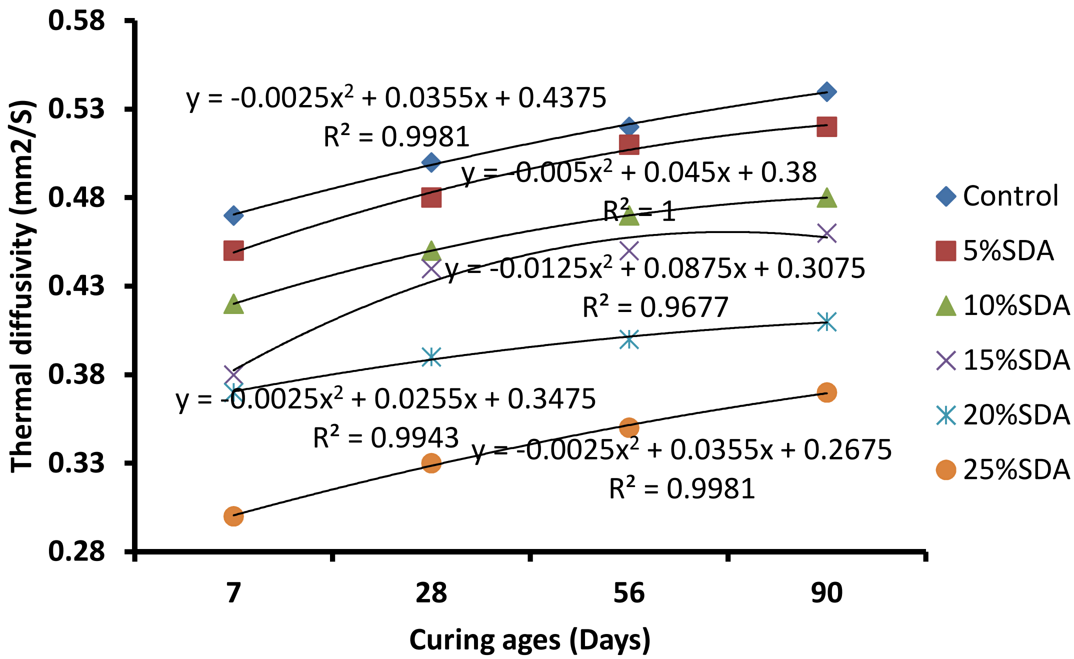

Figure 8: Thermal diffusivity of SDA concrete at elevated temperature

The corresponding values obtained for thermal diffusivity at elevated temperature generally followed the same trend as that obtained for room temperature but the values were higher than those obtained at room temperature (Figure 8). The increase in thermal diffusivity value indicates that SDA concrete would undergo a faster temperature change or allow more rapid heat flow through it under an imposed fluctuating thermal environment. Low thermal diffusivity will transfer heat slowly and have a larger amount of heat storage. Material with low thermal diffusivity will respond slowly to an imposed temperature differences and are effective thermal mass elements in a building. This is in consonance with previous findings of (Amana *et al.* (2014) for thermal performance of rubber concrete but lower than the results reported by Oladunjoye and Sanuade (2012) for thermal diffusivity of soils. Results of analysis of variance showed that the independent factor (i.e. SDA content and curing age), when considered individually and jointly had significant effects on the thermal diffusivity of the concrete at 95% confidence level. A second order polynomial describes the relationship between the thermal diffusivity and curing age at both room and elevated temperatures with R^2 ranging between 0.96 and 1.00.

Conclusions

Based on the findings in this study, the following conclusions can be drawn:

i. SDA is a suitable material for use as a pozzolan, since it has the sum of SiO_2, Al_2O_3 and Fe_2O_3 greater than 70% as required by ASTM C618.
ii. The thermal properties studied increased with increased curing age and temperature but reduced with increased percentage SDA replacement and still exhibits an acceptable workability up to 25% SDA replacement.
iii. Second order polynomial equations best describe the relationship between the thermal properties studied and the curing age of the SDA
iv. Thermal conductivity of SDA concrete decrease with increase in temperature and was able to reduced k of pure concrete by 36.1% with 25% SDA replacement but.
v. Thermal diffusivity of concrete decreases by 37.9% with 25% SDA content but increased with temperature increase. .
vi. The specific heat capacity of SDA concrete increase with curing age and decreases with SDA replacement. It also decreased with increase in temperature.
vii. SDA concrete exhibits better insulating properties and are more thermally suitable for habitable and farm structures than Ordinary Portland cement concrete.

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