A Study of Thermal Conductivity of Corn Cob Ash Blended Cement Mortar.

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ABSTRACT

This study investigated the thermal conductivity of corn cob ash (CCA) blended cement mortar. Nine classes of CCA blended cements were employed with the CCA content ranging from 0% to 25%. The 0% CCA replacement involved the use of normal ordinary Portland cement and it served as the control. The mix proportions of cement: sharp sand used were 1:1, 1:2, and 1:3 with water-to-binder ratio ranging between 0.26 and 0.29. Thermal conductivity test was performed using 50 x 50 x 15 mortar cube specimens cast in wooden moulds in pairs. The steady state heating method involving the use of three – blocks of brass was used for conducting the test with a heater made of nichrome wire wound round a ceramic rod. The final temperature difference obtained over a period of continuous heating for eight hours was used in determining the thermal conductivity. The thermal conductivity of CCA-blended cement specimens decreased steadily as the CCA percentage increased. For 1:1 mix proportion; the thermal conductivity decreases from 1.80W/m^{0}C to 0.69W/m^{0}C when the CCA percentage replacement increases from 2% to 25% as against the control value of 2.40W/m^{0}C. Similar trend was observed for 1:2 and 1:3 mix proportions. It was concluded that CCA blended cement enhances the insulation potential of the mortar.

(Keywords: corn cob ash, CCA, blended cement, thermal conductivity, pozzolanic properties)

INTRODUCTION

Portland cement, as an ingredient in concrete, is one of the most widely used construction materials, especially in developing countries. The current cement production rate of the world is approximately 1.2 billion tons/year. This is expected to grow to about 3.5 billion tons/year by 2015. This increasing demand for cement is expected to be met by partial cement replacement (Coutinho, 2003). The search for alternative binder or cement replacement materials led to the discovery of the potentials of using industrial by-products and agricultural wastes as cementitious materials. If these fillers have pozzolanic properties, they impart technical advantages to the resulting concrete and also enable larger quantities of cement replacement to be achieved (Hossain, 2003).

Corn cob is the agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa. According to Food and Agriculture Organization (FAO) data, 589 million tonnes of maize were produced worldwide in the year 2000(FAO, 2002). The United States was the largest maize producer having 43% of world production. Africa produced 7% of the world's maize (IITA, 2002). Nigeria was the second largest producer of maize in Africa in the year 2001 with 4.62 million tonnes. South Africa has the highest production of 8.04 million tonnes (FAO, 2002). Thus, there are abundant corn cobs which serve as raw material for the type of blended cement being studied.

Previous research efforts on the use of corn cob ash (CCA) as a pozzolan (Adesanya, 1996, 2000, 2001) involved mixing of the CCA with ordinary Portland cement at the point of need. This study involved the use of CCA blended cement produced in the controlled environment of a factory as reported by Adesanya and Raheem (2009a). While some research has been carried out on the compressive strength of concrete with CCA as partial replacement in cement (Adesanya, 1996, 2001; Adesanya and Raheem, 2009a, 2009b), the study of the effect of CCA on thermal conductivity are scarce in the literature.

The thermal conductivity of concrete is of interest due to its relevance to the development of temperature gradients, thermal strains and cracking in the very early life of concrete, as well as the thermal insulation provided by concrete during its service life. The major cause of the temperature differential in a concrete element is the generation of heat by the hydration of cement. It is possible to reduce this heat by choosing a Portland cement with a chemical composition that leads to a low rate of heat development. Blended cements have been known to possess this trait depending on the particular type of pozzolan incorporated (Fu and Chung, 1999; Neville, 2000; Demirboga, 2003).

There are various testing devices for measuring thermal conductivity. Kim *et al*. (2003) identified three methods of measuring thermal conductivity as follows:

(a) Two-Linear-Parallel-Probe (TLPP) method
(b) Plane-Heat-Source (PHS) method and
(c) Hot-Guarded-Plate (HGP) method.

The third method employs steady state heat flow in which the heat flux does not change with time. Two versions of this method have been used in previous studies on thermal conductivity at Obafemi Awolowo University Ile-Ife. These are: the Plate Thermal Conductometer used by Adesanya (2001) and Three-Blocks-of-Brass employed by Osunade (1991). Both methods yielded satisfactory results. The three-blocks-of-brass version was adopted for this research based on its availability and simplicity of application.

This study investigated the thermal conductivity of CCA blended cement mortar with a view to ascertaining its insulation characteristics.

EXPERIMENTAL PROCEDURE

Materials

The CCA blended cement used was produced in accordance with the procedure set out in Adesanya and Raheem (2009a). The chemical composition of CCA, which makes it possible to be used as a pozzolan as determined from Adesanya and Raheem (2009a) is presented in Table 1. Nine classes of CCA blended cements were employed with the CCA content ranging from 0% to 25%. The 0% CCA replacement involved the use of normal ordinary Portland cement and it serves as the control. Sharp sand was used as fine aggregates and it was obtained from Ogbomoso, Nigeria

Table 1: Chemical Composition of Corn Cob Ash (CCA).

Chemical Constituents	Percentage Composition (%)			
	Sample 1	*Sample 2*	*Sample 3*	*Average*
SiO_2	67.33	65.39	66.41	66.38
Al_2O_3	7.34	9.14	5.97	7.48
Fe_2O_3	3.74	5.61	3.97	4.44
CaO	10.29	12.89	11.53	11.57
MgO	1.82	2.33	2.02	2.06
SO_3	1.11	1.10	1.01	1.07
Na_2O	0.39	0.48	0.36	0.41
K_2O	4.20	4.92	5.64	4.92
Total $S1O_2 + Al_2O_3$	74.67	74.53	72.38	73.86

Specimen Preparation

Specimen preparation for thermal conductivity test was performed using 50 x 50 x 15mm mortar cubes of mix proportions 1:1, 1:2 and 1:3. The cubes were prepared using CCA blended cements with various percentages of CCA replacement as produced and sharp sand. Batching was by weight and the water binder ratio ranges between 0.26 and 0.29. The specimens were cast in wooden moulds in pairs, de-moulded after 24hours, air-cured for 15 days and oven-dried for 24hours to ensure complete removal of their water content. Nine batches of mortar were prepared for each mix proportion, each batch corresponding to each of the nine percentage CCA replacement of 0%, 2%, 4%, 6%, 8%, 10%, 15%, 20%, and 25% in the blended cement used.

Thermal Conductivity Test

The steady state heating method involving the use of three – blocks of brass as employed by Osunade (1991) was used for conducting the test. The three blocks of brass (labeled L, C, R) have the dimensions 50mm x 50mm each, and a thickness of 15mm, 30mm and 15mm respectively. A heater made of nichrome wire wound round a ceramic rod was used. The experimental set up for the test is shown in Figure 1.

The heater was connected in series to the ammeter, voltmeter, rheostat, power supply and key as shown in Figure 1. The power supply used was a 12 volt car battery. The rheostat was adjusted until a minimum current of 1 ampere was supplied for the heating. The final temperature difference obtained over a period of continuous heating for eight hours was used in determining the thermal conductivity (k) using Equation 1.

$$K = \frac{V I d}{A(\theta_1 - \theta_2)} \quad \textbf{(1)}$$

where:
V = Voltage (Volts)
I = Current (Ampere)
d = Thickness of sample (m)
A = Cross sectional area of sample
$\theta_1 - \theta_2$ = Temperature difference between the faces (^{0}C)

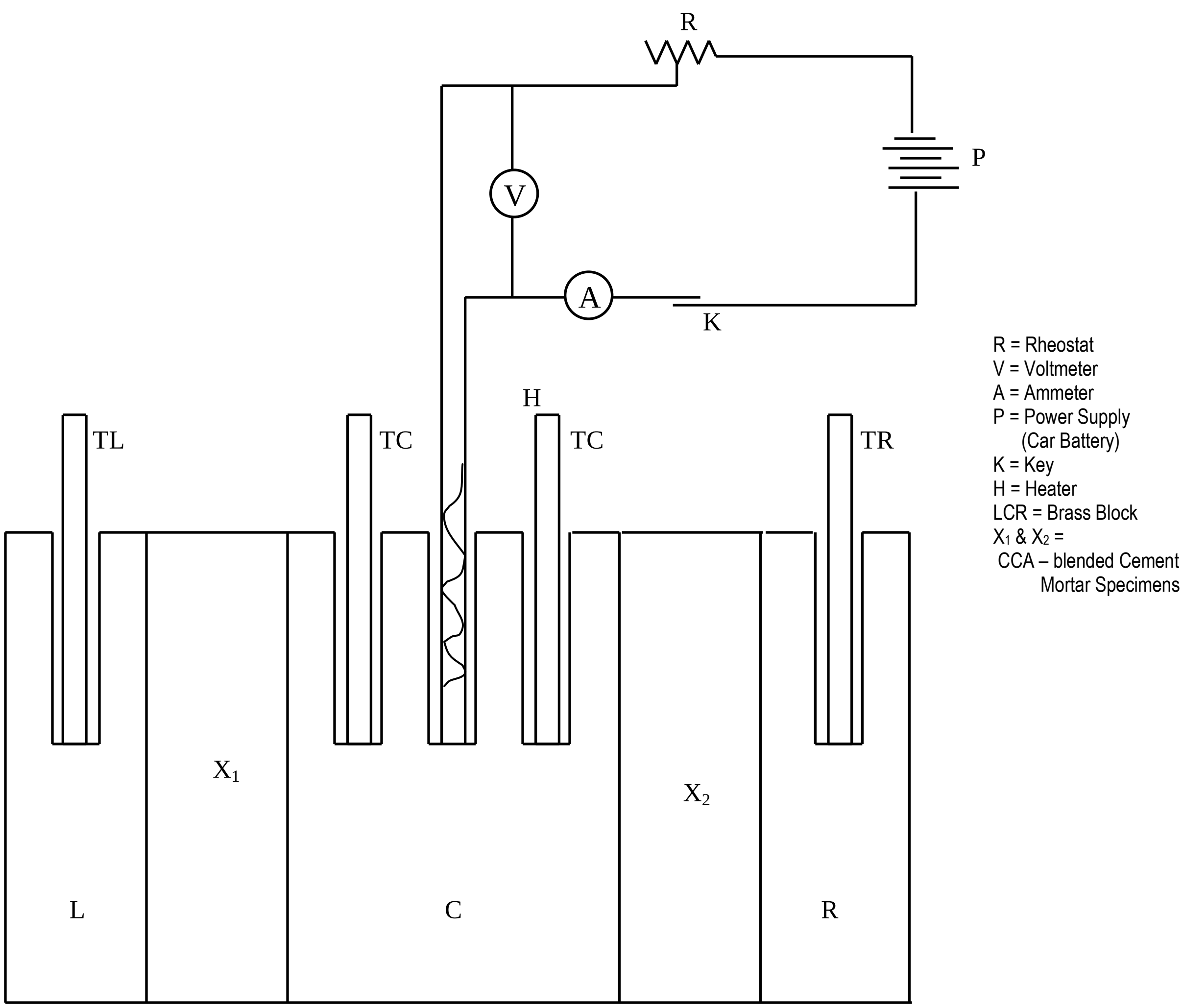

Figure 1: Experimental Set-up for Thermal Conductivity Test.

RESULTS AND DISCUSSION

The results of the thermal conductivity of CCA-blended cement mortar cubes for the three mix proportions considered are presented in Tables 2 to 4. Table 2 indicated that for 1:1 mix proportion; the thermal conductivity decreases from 1.80W/m^{0}C to 0.69W/m^{0}C when the CCA percentage replacement increases from 2% to 25% as against the control value of 2.40W/m^{0}C.

Table 2: Thermal Conductivity of Blended Cement Mortar Cubes (mix proportion 1:1).

Percentage CCA Replacement (%)	Final Temperature Difference (°C)	Thermal Conductivity (W/m°C)
0	3.0	2.40
2	4.0	1.80
4	5.0	1.44
6	6.5	1.11
8	7.0	1.03
10	7.5	0.96
15	8.5	0.85
20	9.0	0.80
25	10.5	0.69

Table 3 revealed that for 1:2 mix proportion; the thermal conductivity decreases from 1.44W/m^{0}C to 0.63W/m^{0}C when the CCA percentage replacement increases from 2% to 25% as against the control value of 1.60W/m^{0}C.

Table 3: Thermal Conductivity of Blended Cement Mortar Cubes (mix proportion 1:2).

Percentage CCA Replacement (%)	Final Temperature Difference (°C)	Thermal Conductivity (W/m°C)
0	4.5	1.60
2	5.0	1.44
4	5.5	1.31
6	7.5	0.96
8	8.0	0.90
10	9.0	0.80
15	9.5	0.76
20	10.0	0.72
25	11.5	0.63

Table 4 showed that for 1:3 mix proportion; the thermal conductivity decreased from 1.11W/m^{0}C to 0.51W/m^{0}C when the CCA percentage replacement increased from 2% to 25% as against the control value of 1.20W/m^{0}C.

Table 4: Thermal Conductivity of Blended Cement Mortar Cubes (mix proportion 1:3).

Percentage CCA Replacement (%)	Final Temperature Difference (°C)	Thermal Conductivity (W/m°C)
0	6.0	1.20
2	6.5	1.11
4	7.5	0.96
6	8.0	0.90
8	8.5	0.85
10	9.5	0.76
15	10.5	0.69
20	12	0.60
25	14	0.51

The reduction in thermal conductivity could be attributed to the presence of CCA in the blended cement used. This is in line with the findings of Adesanya (2001), Demirboga and Gul (2003) and Kim *et al.* (2003) which stated that thermal conductivity decreases with the addition of pozzolanic materials in concrete. According to Demirboga and Gul (2003), the reduction in thermal conductivity is partly due to the high silica content of the pozzolan (CCA in this case). This could be confirmed from the result of chemical composition of CCA in Table 1 as silica alone represents over 60% of the entire composition.

Figure 2 showed the effect of CCA percentage replacement on the thermal conductivity for the three mix proportions considered. The plot was carried out using polynomial of the second order (quadratic). The coefficient of determination (R^2) obtained for the mix proportions 1:1, 1:2 and 1:3 were 0.919, 0.948 and 0.985, respectively. This indicates that there is a strong relationship between the CCA percentage replacement and thermal conductivity for all the three mix proportions considered. Figure 2 also indicated that the richer the mix proportion, the higher the thermal conductivity of the specimens.

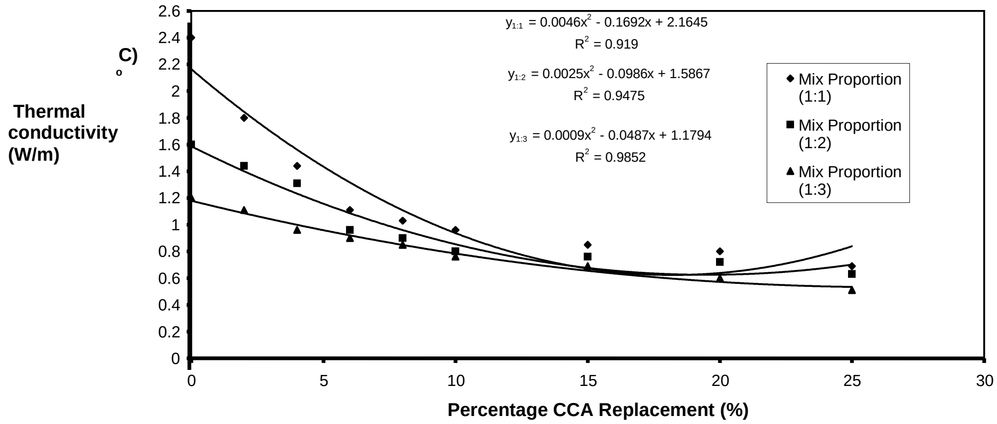

Figure 2: Effect of Percentage CCA Replacement and Mix Proportions on Thermal Conductivity of Blended Cement Mortar Cubes.

This is because the specific gravity of Portland cement is higher than that of other ingredients in the mix, thus leading to an increase in the density of concrete and consequently, increases in the thermal conductivity (Uysal *et al.,* 2004). Thus, in order to minimize thermal conductivity, the cement content in mortar should be kept to the barest minimum. Hence, mortar with 1:3 mix proportion with 25% CCA content and having the lowest thermal conductivity value of 0.51W/m^{0}C is recommended for wall plastering and floor screeding in order to improve the insulation properties of a building.

CONCLUSION

From the results of the test performed, it could be concluded that the incorporation of CCA in blended cement mortar cubes decreases thermal conductivity and improves the insulation properties of the specimens. The implication of this is that the use of CCA- blended cement in mortar used for plastering and floor screeding, would improve the thermal comfort in buildings thereby reducing the cost of energy required for cooling thus, leading to energy conservation.

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