American Journal of Engineering and Applied Sciences 7 (1): 137-148, 2014
ISSN: 1941-7020

doi:10.3844/ajeassp.2014.137.148 Published Online 7 (1) 2014 (http://www.thescipub.com/ajeas.toc)

INVESTIGATING EFFECTS OF INTRODUCTION OF CORNCOB ASH INTO PORTLAND CEMENTS CONCRETE: MECHANICAL AND THERMAL PROPERTIES

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Received 2014-02-05; Revised 2014-02-13; Accepted 2014-03-31

ABSTRACT

The purpose of this study was to evaluate the benefits of replacing Ordinary Portland Cement (OPC) with Corncob Ash (CCA) blended cements. The cement industry contributes considerable amount of Carbon Dioxide (CO_2) emissions into the atmosphere. The main contribution of CO_2 emissions from cement production results from the process of creating Calcium Oxide (CaO) from limestone ($CaCO_3$) commonly known as the calcination process. Blending OPC with a pozzolanic material will assist in the reduction of CO_2 emissions due to calcination as well as enhance the quality of OPC. There are various pozzolanic materials such as fly ash, rice husk, silica fume and CCA that could be promising partial replacement for OPC. In this study, CCA will serve as the primary blending agent with OPC. An experiment was performed to designate an appropriate percentage replacement of CCA that would comply with specific standards of cement production. The experimental plan was designed to analyze compressive strength, workability and thermal performance of various CCA blended cements. The data from the experiment indicates that up to 10% CCA replacement could be used in cement production without compromising the structural integrity of OPC. In addition, it was found that the compressive strength and workability of the resulting concrete could be improved when CCA is added to the mixtures. Furthermore, it was shown that the introduction of 10% CCA can lead to significant reduction in thermal conductivity of the mixture.

Keywords: Ordinary Portland Cement, Corncob Ash, Workability, Thermal Conductivity

1. INTRODUCTION

CO_2 emissions are becoming an extremely distressing issue that continues to negatively impact the environment. As CO_2 emissions continue to grow, the global temperature continues to increase The Economist, 2013. The increase of global temperature leads to melting polar ice caps and depleting the ozone. According to the Green Building Council, construction and transportation contributes to over 50% of total CO_2 emissions in the United States alone. In 2004, residential and commercial building construction was responsible for 2,236 million metric tons of CO_2 emissions, approximately 39% of total CO_2 emissions (Gorkum, 2010). With the rapid growing construction industry, it is imperative to develop and promote sustainable design practices to address CO_2 emission issues associated with cement and concrete production.

Concrete is the second most consumed substance in the world (Adesanya and Raheem, 2009a). Currently cement production is at 1.2 billion tons per year and is expected to grow to 3.5 billion tons per year by the year of 2015 (Adesanya and Raheem, 2009b). Cement

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production is responsible for 5% of total CO_2 emissions globally (Gorkum, 2010). For every ton of cement produced, anywhere from 0.73-0.99 tons of CO_2 is emitted (Hasanbeigi *et al*., 2012). As cement production exponentially increases, it is essential to focus on ways to create alternative production processes to reduce the carbon footprint throughout the world. Cements are produced by mining limestone from a quarry and shipping the limestone to a mill in order to begin the grinding process (PCA, 2014). The limestone is placed into a primary crusher to reduce the size of the stones. Stones that are high in calcium carbonate are crushed separately than the stones with low calcium carbonate. The crushed limestone is then mixed with other minerals and various raw materials. Blended cements' chemical composition varies from one quarry to another but typically the main components of OPC are Calcium Oxide (CaO), Silica (SiO_2), Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3). After the materials and minerals are added, they are then heated in a kiln to promote the bond between the raw meals beginning the calcination process. Finally the molten meal is cooled and the clinker is created. The calcination process is responsible for 50% of CO_2 emissions, 45% due to burning fuel and 5% due to mining and transportation (Hasanbeigi *et al*., 2012). Therefore, reducing the calcination process by partial replacement of OPC with Corncob Ash (CCA) is expected to yield a significant reduction in CO_2 emissions. Corn is the most widely planted crop in the world. The United States is responsible for 43% of the world's corn production, recording 9 billion bushels in 2001 (NASS, 2011). Since 2001, corn production in the United States has increased, recording 13 billion bushels in 2011 (NASS, 2011). North Carolina alone was responsible for over 76 million bushels of corn in 2011. Each bushel of corn contains around 40 to 60 ears of corn (NASS, 2011; Oladipupo and Fetus, 2012). Corncob is a readily available biomass that when not disposed of properly can pollute the land, air and water. Typically, corncob is only used for animal feed and in few cases alternate fuel (Biello, 2008).

There has been several studies on modifying Portland cement or partially replacing cement with other pozzolanic materials to reduce CO_2 emission associated with production of cement clinker. In addition, previous studies investigated the significance of the Lime Saturation Factor (LSF) in OPC clinker. Average LSFs are approximately around 97, ranging between 90 and 102 (Hasanbeigi *et al*., 2012). Cements with high LSFs have several drawbacks; for instance, higher temperatures are required to create clinker with high LSFs. Creating clinker with high temperature results in denser clinker, making it more difficult to grind. LSFs higher than 102 will result in large amounts of free lime effecting the soundness and compressive strength of the final product. A smaller LSF means less limestone in the raw meal, which reduces the level of reactivity and transformation of $CaCO_3$ to CaO. This in turn, leads to large portions of CO_2 emissions (Hasanbeigi *et al*., 2012). However, when percentage of CCA in cement increases, the LSF decreases. It has been found that the LSF can be decreased from 92 to 72 with introduction of 25% Corncob Ash (CCA) into OPC (Adesanya and Raheem, 2009a; 2009b). To further investigate the properties of CCA cement, mortar cubes were created and tested through a steady state heating method. A final temperature was obtained over continuous heating for 8 h. The thermal conductivity found to be decreased steadily with increasing CCA percentages in each blend; illustrating that CCA blended cements can be promising candidate for use in thermal insulation applications (Raheem and Adesanya, 1996). Other researchers studied the effects of kinetics on fly ash blended cements hydration at different curing temperatures. It was shown that at 20 and 35°C curing temperature, fly ash retards the hydration of cement in the early period while it accelerates the hydration in the later period (Narmluk and Nawa, 2011). The cylindrical shape of fly ash has a positive impact on the rheological properties of cement. In fly ash blends, the OPC is responsible for producing calcium hydroxide while the fly ash is responsible for consuming the calcium hydroxide during the pozzolanic reaction (Narmluk and Nawa, 2011).

Pozzolanic cement blends have significant effects on corrosion and compressive strength compared to that of OPC (Guneyisi *et al*., 2005). In a previous study, various CCA blended cements were tested at different curing ages including Wet Curing (WC), Uncontrolled Curing (UC) and Controlled Curing (CC). During WC, specimens were immersed in 20±2°C water. In UC, specimens were air cured at uncontrolled temperatures and relative humidity. In CC, specimens were immersed in 20±2°C water for 7 days and then air cured in a room at 20±1°C and 50±5% relative humidity. When testing corrosion, the time it took for OPC to begin cracking was within the range of 3-7 days while the blended cements were in a range of 2-18 days depending on the type, water to cement ratio, curing condition and age at testing. The accelerated corrosion test indicated that blended cements had superior performance, taking longer to begin cracking and experience corrosion compared to OPC at similar curing condition and testing ages (Guneyisi *et al*., 2005). The results also indicated that both OPC and blended cements in UC had lower compressive strength compared to CC and WC conditions. In addition, in most cases, the strength gain in blended cements was higher than that of OPC, especially under CC and WC conditions. With 28 day curing age, blended cements found to have lower compressive strengths than OPC, but strength found to increase as the curing age increased (Guneyisi *et al*., 2005). In another study of fly ash blended cements, it was found that a cementitious binder may be produced with simply fly ash, fluorogypsum and lime sludge, consequently entirely eliminating the necessity of using OPC. Fly ash is a pozzolanic material, which is often treated as waste. Over 100 million tons of fly ash are available as waste from thermal power plants in India alone (Singh and Garg, 2007). As such several researchers developed a variety of blends and tested them for compressive strengths after 28 days curing age. One of the highest compressive strengths recorded was that of a blend without presence of OPC. Aforementioned blend consisted of only fly ash, fluorogypsum and lime sludge (Singh and Garg, 2007). Similar to fly ash, lime sludge also is a waste product that can be recycled and easily obtained. Lime sludge is a by-product of water purification. Approximately 10,000 tons of lime sludge is produced annually in a single water plant (Massillon water plant in Ohio. There are thousands of water plants similar to Massillon across the United States (Lang, 2012). Fluor gypsum is the waste product of hydrofluoric acid. Over 6.5 million tons of the by-product gypsum, (photo gypsum and Fluor gypsum) are produced annually from several phosphatic and hydro-fluoric acid industries in India (Singh, 2012). The chemical composition of fluorogypsum consists of 1.32% F, 0.65% SiO_2, 0.65% (Al_2O_3 + Fe_2O_3), 41.19% CaO and 56.10% SO_3. Due to the high concentration of lime, fluorogypsum can be a promising candidate to react with pozzolanic materials. As such several researchers used this material to create full size bricks including different percentages of sawdust, rice husk and vermiculite along with fluorogypsum. The optimum quantity of percent additions were 10% of sawdust, 5% of rice husk and 10% of vermiculite. The bricks were tested for physical appearance, compressive strength, water absorption and efflorescence. High strength plaster could be developed from fluorogypsum waste with a mixture of chemical activators such as $Ca(OH)_2$, $CaCl_2$ and Na_2SO_4. In addition, they found that 15-20% lime sludge could be added to the binder to economize production without sacrificing compressive strength (Singh and Garg, 2009). When modifier or partial replacement of cement is used, there is always a concern about the change of permeability and potential of Alkali-Silica Reaction (ASR). ASR involves reaction between the active silica constituents of the aggregate and the alkalis in cement, resulting in the formation of alkali-silicate gel. ASR is what destroys the bond between the aggregate and surrounding hydrated cement paste (Adesanya and Raheem, 2010). In a previous study, it was determined that OPC is the major source of alkali in the concrete. Alkalis are provided in smaller amounts from fly ash. Mineral admixtures reduce ASR expansions by various mitigation techniques such as reducing the alkali content in the concrete mix, consuming the calcium hydroxide present and reducing concrete permeability (Touma, 2000). Initially, permeability begins to increase with CCA replacement due to the lack of calcium hydroxide present to react with the excess silica in CCA blends. The lack of reaction increases the porosity of the mixture allowing for more water absorption. As higher contents of calcium hydroxide become available, the reaction continues decreasing the porosity and the permeability. This in turn leads to a more sound mixture. Calcium hydroxide is most vulnerable to a chemical attack, when a higher content of calcium hydroxide is present the more likely the mixture will be subject to attack. However, as the porosity and permeability decrease with more CCA percentage replacement, the mixture becomes sounder and less permeable (Adesanya and Raheem, 2010).

The research presented in this study focused on evaluating the effects of replacing portions of OPC with various percentages of CCA. The objective was to determine optimized percentage of CCA replacement that will yield the optimum compressive strength, workability, flow and thermal conductivity while complying with cement production standards. To do so following tasks were undertaken:

- Develop various cement blends by implementing an incremental increase in percentage of CCA
- Compare the flow of hydraulic CCA blended cements using the flow table test

- Determine the effect of various CCA blended cements on compressive strength
- Compare the viscosity, torque and shear stress of various CCA blended cements
- Use the flow table test to observe the change of workability as a function of time for the blended cements
- Compare the effect of various CCA blended cements on thermal conductivity

2. EXPERIMENTAL PROGRAM

In order to achieve the objectives of this study, an experimental plan was developed to create CCA blended cements. As such three different cement, sand and water-cement (w/c) ratios were used. CCA percentages include 0, 5, 10, 15 and 20% CCA replacement. Specimens were prepared and cured for 90 days. For all specimens compressive strength test was conducted following C109/C109M-12. All tests were conducted for three replicates. In addition, rheological properties of the mortar were studied using a Brookfield (DV-III Ultra) rotational viscometer. The viscosity, torque and shear stress of each blend was recorded at both 5 and 10 RPM. Data were recorded with 5-min increments over a span of 20 min. Furthermore, to compare the workability of 0, 5, 10 and 15% CCA blends, the flow table test was performed complying with ASTM C1437-07 standard. Hydraulic cement was placed on a Flow Table Apparatus and the length of flow was measured. Finally, thermal conductivity tests were carried out to determine thermal conductivity of the new composite. A heat transfer measurement device was designed and constructed according to the standards to measure thermal conductivity of the CCA concrete specimens. Data were collected periodically every minute over the span of approximately an hour.

2.1. Materials

The Corncob ash used in this study was produced by grinding dried corncobs to approximately 4.0 mm diameter to enhance appropriate combustion. It should be noted that failure to appropriately grind corncobs prior to burning can lead to adverse effects on the pozzolanic properties of the CCA. Corncobs were then burnt in the open air using a stove fueled by natural gas in order not to compromise the chemical composition of the finished product. Portland cement type I was used and the sand was Saturated Surface Dry.

2.2. Specimen Preparation

Four different CCA mixtures were developed along with one control sample (OPC without CCA). These mixtures were prepared in the laboratory using 0, 5 10 15 and 20% replacement by weight of CCA. For both the compression test and thermal conductivity test, a mixture of 45% water to cement (w/c) ratio was used. The mixture proportion of cement to sand was 1:3, 25% cement to 75% sand. Cubic shape steel molds (50×50×50 mm) were used to cast the mortar and make concrete cubes for compressive strength test. A total of 15 cubes were casted (three cubes for each CCA blend). For the thermal conductivity test, 305 mm^2 by 25 mm thick concrete blocks were created using pre-made wooden molds.

2.3. Mixing and Preparing Specimens

A mixer type Hobart HL 200 was used to mix the materials. Sand, cement and corncob ash were placed in the mixer at the same time. The materials were dry-mixed for 2-3 min. After a homogenous distribution of the materials, mixing water was added gradually and mixed for additional 4 min. After confirming that the mix was workable, the mix was poured into the molds. The molds used were specially made for this test. The molds were squares of 304.8 mm by 304.8 and 25.4 mm depth (12×12×1 in.). After placing mortar into the mold, the mold was vibrated on a vibrating table for 30-60 sec. Then excess mortar was removed and the specimen's is finished with a steel trowel. The specimens were then covered with plastic for the first 24 h. The specimens were then demolded and placed in the cure tank for 90 days. After 90 days, the specimens were removed from the curing tank and dried in an oven for 24 h at a temperature of 21°C (70°F).

3. TEST PROCEDURES

3.1. Flow Table Test

The flow table test was performed in accordance with ASTM C1437-07 Standard Test Method for Flow of Hydraulic Cement Mortar. The flow table test determines the flow of hydraulic cement in order to grasp an idea of workability-time of the cement.

3.2. Thermal Conductivity Measurement

A specially designed thermal conductivity measurements device was constructed based on hot box apparatus. The principle of measurement is to place the specimen between two boundaries held at constant temperatures. One side was heated by a heat source and the other side was kept at room temperature. The box was constructed from homogeneous materials that have stable thermal properties and have high thermal resistance and good mechanical properties. The structure of the box shown in **Fig. 1** was 113 cm height, 40.64 cm width and 40.64 cm deep (44½×16×16 in.). The thickness of the surrounding chamber was 5.08 cm (2 in.). In order to minimize heat losses to its surroundings, the chamber was constructed of extruded Polystyrene (XPS) layer placed between two layers of Maple plywood with a thickness of 0.635 cm (¼ in.) each. The three layers were assembled using a heavy duty construction adhesive.

To measure heat flux, the device was equipped with HFP01 heat flux sensors (**Fig. 2a**). The body of HFP01 was composed of ceramics-plastic and a thermopile embedded in the plastic ceramic composite (thermopile is a set of connected thermocouples that can measure a small quantity of heat flux). To collect the data from HFP01, an accurate voltmeter that has millivolt range was used. HFP01 sensor was calibrated using a guarded hot plate according to ASTM C 177. It has sensitivity (E) of 61.37 $\mu V/W/m^2$. After the voltage output was collected, the heat flux was calculated based on the following formula Equation 1:

$$Q = V / E \tag{1}$$

Where:

Q = Heat flux W/m^2,
V = Measured voltage and
E = Sensor sensitivity (61.37 $\mu V/W/m^2$)

To measure temperature differences across the specimen, three temperature data loggers are placed from each side of the specimen. HOBO data logger type H08-007-02 and BoxCar 3.7 Software were used to measure temperature (**Fig. 2b**). The data logger has two internal temperature sensors and two external sensors. Further, the data logger is programmable in term of time increment and the start and end time.

3.3. Calibration of the Measurement Device

The device was calibrated by testing materials with known thermal conductivity. Four different construction materials were tested for thermal conductivity. The dimensions of the samples were 30.48×30.48×2.54 cm (12×12×1 in.). The samples include: Gypsum board (drywall) with 1.27 cm (½ in.) thick; oriented strand board (OSB) with 1.27 cm (½ in.) thick; Plywood with 1.27 cm (½ in.) thick; Mortar with 2.54 cm (1 in.) thick.

3.4. Test Setup

A schematic of thermal conductivity test setup is shown in **Fig. 3**.

The following testing steps were followed for each test: (a) Specimen was mounted and sealed from all sides; (b) The heat flux sensor was attached to the surface of the specimen. Heat flux was recorded when it reached steady state; (c) Three temperature loggers were mounted to each side of the specimen using double sided tape. The temperature logger was placed in such way that there was a temperature logger placed across from it on the other side; (d) the door of the box was tightly closed and sealed to ensure no heat loss through the edges of the door; (e) turn on the heat source: To reach steady state heat flow, the test was run for an hour and a half; (f) at the end of the test, the data were collected and the thermal conductivity was calculated using Fourier's law (Equation 2):

$$Q = -k\frac{\Delta\tau}{x} \tag{2}$$

Where:

Q = Heat flux W/ m^2 (But/ hr-ft^2)
ΔT = Temperature difference across material section K or °C (°F)
x = Material thickness m (ft) and
k = Thermal conductivity W/m. k (Btu /h-ft-F)

Fig. 1. Adiabatic box photographs

(a) (b)

Fig. 2. (a) HFP01 heat flux sensor, (b) HOBO data logger

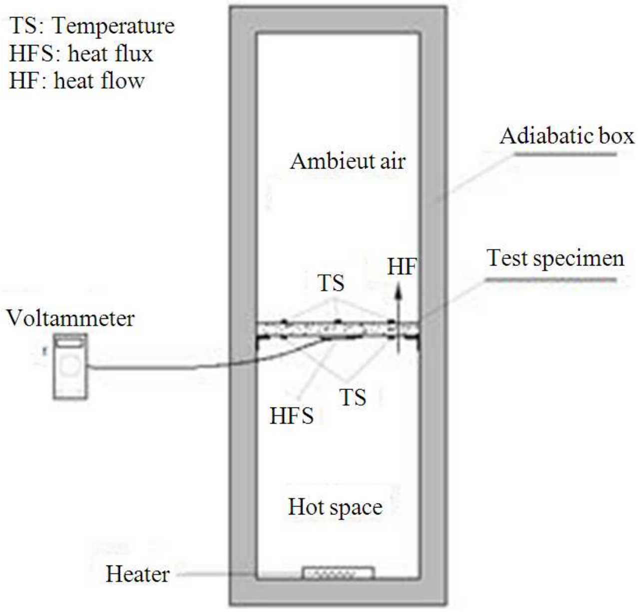

Fig. 3. Schematic of the test set-up

Table 1. Experimental versus reference values

Sample designation	Conductivity (W/ m K) Reference values	Test values
Gypsum board, ½ in thick.	0.17	0.176
Gypsum board, ½ in. thick.	0.17	0.172
Gypsum board, ½ in. thick.	0.17	0.179
Oriented strand board, ½ in.	0.13	0.1495
Plywood with ½ in. thick.	0.138	0.1304
Mortar, 2.54 cm (1 in.) thick.	0.71	0.682
Mortar, 2.54 cm (1 in.) thick.	0.71	0.672
Mortar, 2.54 cm (1 in.) thick.	0.71	0.734

The device was calibrated by conducting the test on materials with known thermal conductivities. The data of theses reference materials were obtained from online sources (www.engineeringtoolbox.com and www.bca.gov.sg) and from engineering handbooks. The thermal conductivity of the reference materials along with the results are listed in **Table 1**. A statistical analysis was carried out to determine a correction factor. The statistical analysis yielded an R^2 value of 0.995 which indicated a strong relation between the reference and experimental values. Using the statistical analysis, an equation was derived (Equation 3) to modify the experimental values, the equation may be expressed as:

$$k_m = 0.964k_{exp}. + 0.011 \quad (3)$$

Where:

k_m = Modified thermal conductivity value and

k_{exp} = Experimental thermal conductivity value

4. EXPERIMNETAL RESULTS

4.1. Flow Table Test

Based on the analysis of the results, it was found that the flow increased as the percent of CCA increased (**Fig. 4**). The flow for the control sample (0% CCA) was approximately 81% flow. The flow began to increase as the percent replacement increased. At 10% the flow reached a max of 119% before gradually starting to decrease.

4.2. Viscosity Test

The viscosity was recorded using a Brookfield rotational viscometer. Five cement blends were created, 0% (control), 5, 10, 15 and 20% CCA replacement. The viscosity, torque and shear stress decreased as the percentage of CCA replacement increased illustrating an extended workability time (**Fig. 5** through 7). Viscosity was measured in Pascal-seconds while torque was measured in percentage of maximum torque capacity for the equipment's spring (0.7187 milli Newton-m). Shear stress was measured in Pascal-seconds. As it can be seen in **Fig. 5**, the 20% replacement yielded the lowest viscosity at both 10 RPM and 5 RPM. In addition it can be seen that specimen without corn cob ash had the highest viscosity among all samples and it showed a significant increase in viscosity after 15 min of mixing (**Fig. 6**).

As it can be seen in **Fig. 7**, the torque measured at 10 rpm was the lowest when 20% CCA was added. In addition, 5% CCA found not be as effective on the toque measurement since the behavior of the mixture with 5% CCA turned out to be very similar to the control mixture with no CCA. However, the torque measurement at 5rpm found to be more sensitive to the percentage of CCA; as it can be seen in **Fig. 8**, the mixture with 5% CCA showed much lower viscosity than those of control mixture. This in turn shows that the mixtures modified with CCA could be more susceptible to shear than OPC samples.

It can be further seen that shear stress varies as the amount of CCA increases. The 20% CCA blend showed the lowest shear stress (**Fig. 9**). In addition, the change of shear stress with time found to be the slowest in the mixture with 20% CCA. This in turn may lead to extended curing time reducing potential occurrence of shrinkage cracks. However, as it was shown in **Fig. 10**, the change of shear stress with time is the highest in the control specimen which may imply fastest curing time.

4.3. Compressive Strength

Fig. 11 shows the results of compressive strength of different percenatage of CCA. In this study, the compression test complying with C109 standard yielded an optimum compressive strength of 35.9 MPa at 90-day curing age with 10% CCA substitution. After that point the increase in CCA resulted in continuous decrease in the compressive strength. This further confirms the results found by (Adesanya and Raheem, 2009b) which showed that compressive strength began to increase with the increase of CCA replacement from zero up to 10% regardless of the curing ageas shown in **Fig. 12**. However, above 10% CCA replacement, the compressive strength began to decrease significantly below the control specimen.

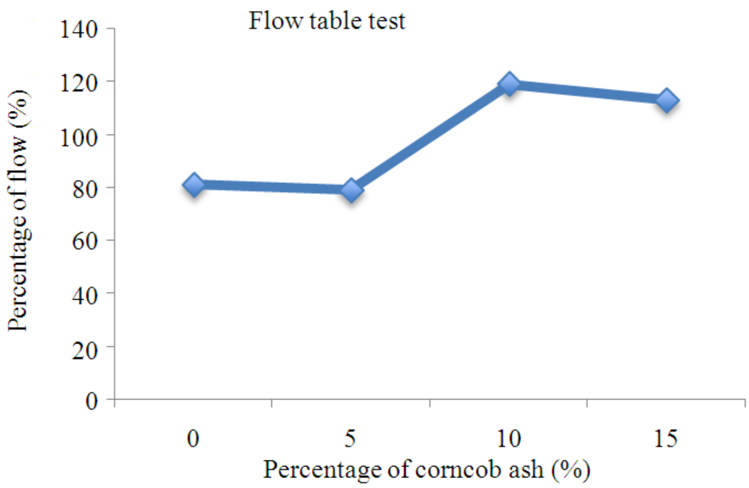

Fig. 4. Flow table test results of corncob ash blended hydraulic cement

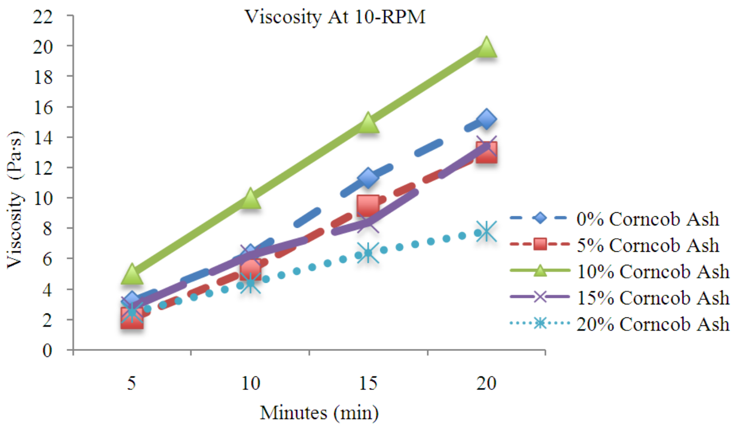

Fig. 5. Viscosity results for blended cements at

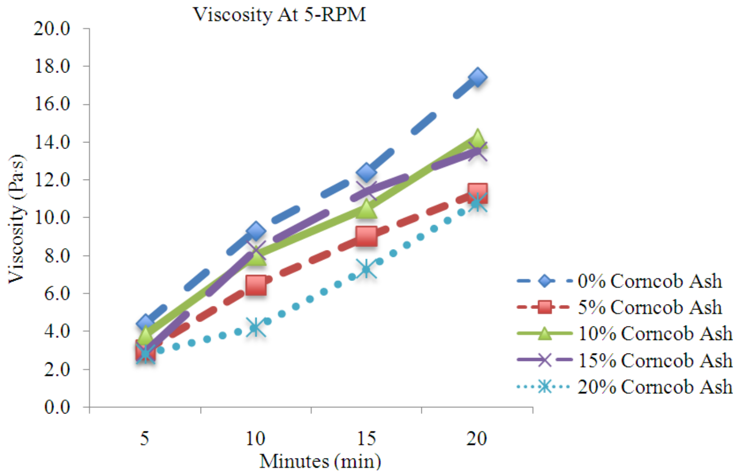

Fig. 6. Viscosity results for blended cements at

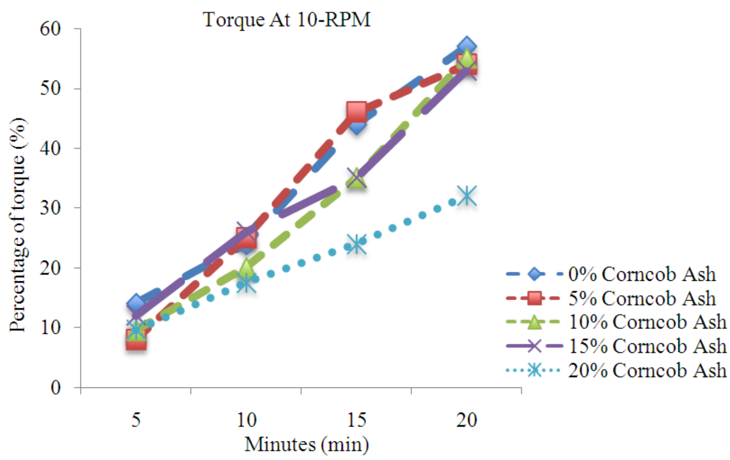

Fig. 7. Torque results for blended cements at

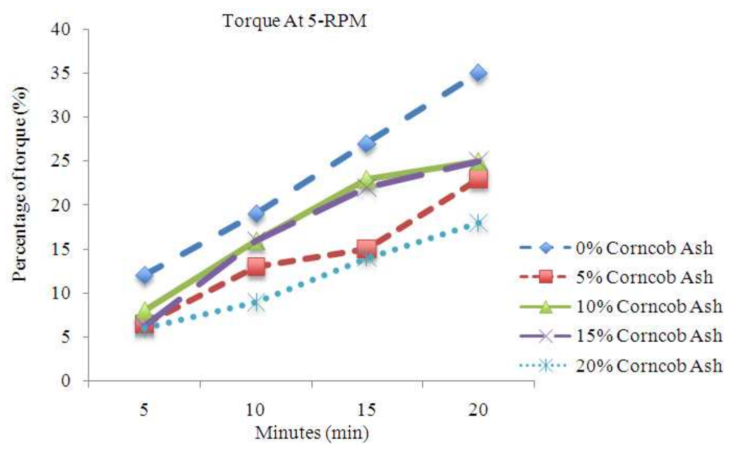

Fig. 8. Torque results for blended cements at

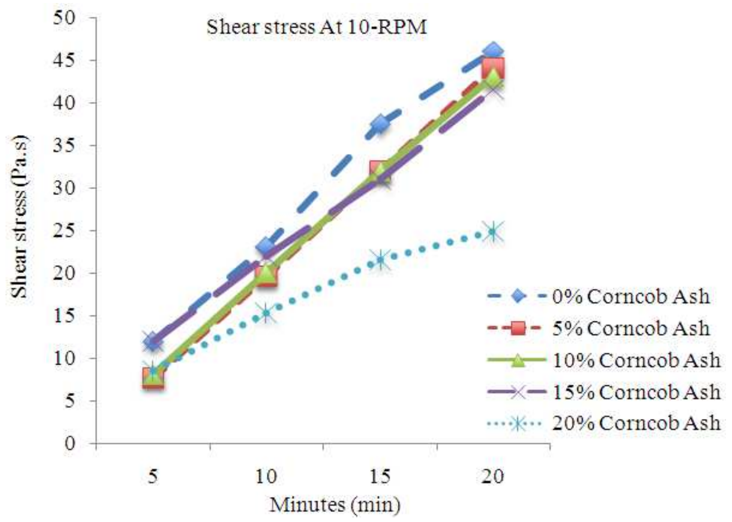

Fig. 9. Shear stress values for blended cements at 0-RPM

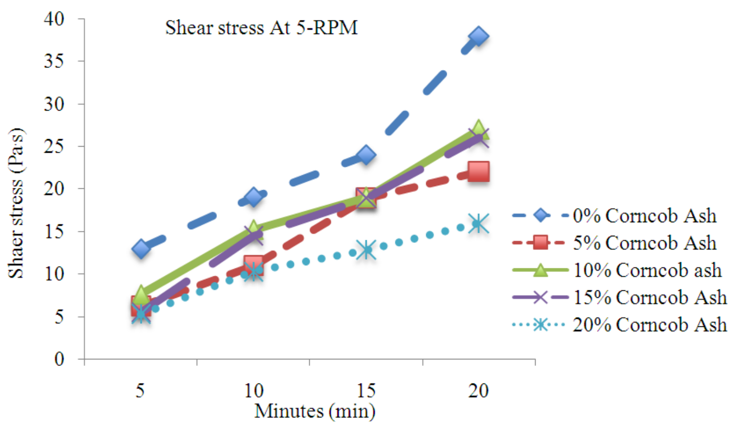

Fig. 10. Shear stress values for blended cements at 5-RPM

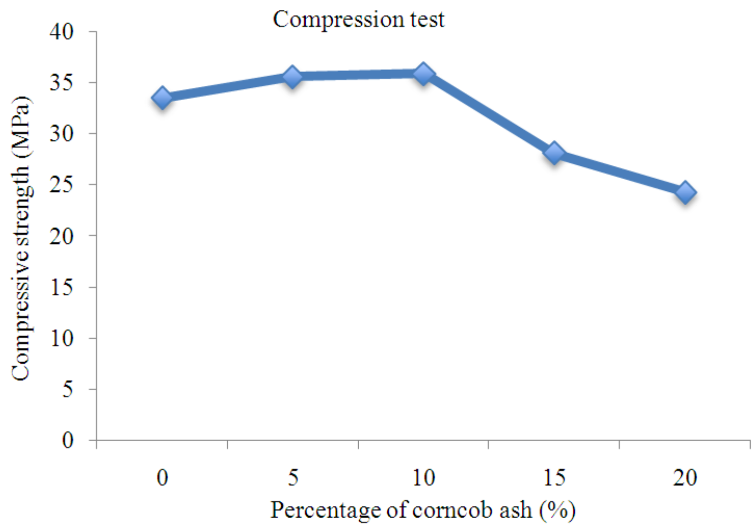

Fig. 11. Compressive strength values for corncob ash blended concrete cubes at 90 days curing age

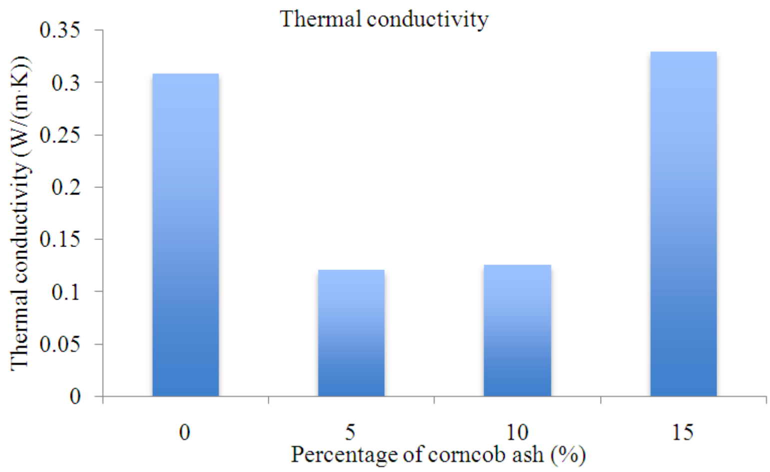

Fig. 12. Thermal conductivity results for blended CCA-cements

4.4. Thermal Conductivity

Corncob has low thermal conductivity; therefore, it could be used as an adequate insulation in building construction. In previous studies the thermal performance of corncob panels were observed by adjusting the thickness of each panel (Paiva *et al*., 2012). It was concluded that thicker corncob particle boards displayed smaller thermal transmission coefficient (Paiva *et al*., 2012). In this study, a similar trend was observed when various percentages of CCA blends were made and tested for thermal conductivity. To conduct the test blocks were placed in a heat box. Then the temperature differences through the blocks were recorded over the span of approximately an hour. Using the information from the heat box, the heat flux (Q) and the thermal conductivity (K) were calculated. It was observed that the thermal conductivity decreased from that of the control specimen when 5 and 10% CCA was added.

5. DISCUSSION

5.1. Flow Table Test

Results indicated that the workability of the corncob ash-portland cement mix was enhanced with the percent increase of CCA.

5.2. Viscosity Test

Five all cement blends, the viscosity, torque and shear stress decreased as the percentage of CCA replacement increased. This shows that the mixtures modified with CCA could be more susceptible to shear than plain mortar samples. In addition, the change of shear stress with time found to be the slowest in the mixture with 20% CCA. This in turn may lead to extended curing time reducing potential occurrence of shrinkage cracks. However, the change of shear stress with time is the highest in the control specimen which may imply fastest curing time.

5.3. Compressive Strength

The compressive strength results reported in this study confirm the results found by (Adesanya and Raheem, 2009b) which showed that compressive strength began to increase with the increase of CCA replacement from zero up to 10% regardless of the curing age. However, above 10% CCA replacement, the compressive strength began to decrease significantly below the control specimen.

5.4. Thermal Conductivity

Incorporating up to 10% of CCA enhances the insulation properties of the mortar.

6. CONCLUSION

For generations, OPC has been the only form of cement available. Considering high amount of cement annual consumption, more sustainable practices in cement production and application could lead to significant CO2 emission. CCA blended cements provide a unique and valuable alternative to conventional methods. Replacing a portion of OPC with up to 10% CCA found to increase the compressive strength of OPC, enhance insulation performance, as well as increase workability time. Apart from the observed structural advantages of CCA blended cements, it is vital to the environmental sustainability to reduce cement production emission. Recycling materials that otherwise would be treated as waste can create endless sustainable construction opportunities.

The purpose of this study was to evaluate the effects of different percentages of CCA replacement in OPC. The tests were performed to determine feasibility of application of CCA without compromising concrete performance properties. Based on the research conducted the following conclusions were made:

- The compressive strength of cement increases from that of OPC with up to approximately 10% CCA replacement at 90-day curing age. However, when percentages of CCA were increased to above 10%, the overall concrete compressive strength was decreased
- Replacing a portion of OPC with approximately 10% of CCA reduce the amount of CO_2 emissions associated with cement production, while maintaining structural integrity of the concrete
- Workability time of CCA blended cements increases with the increase of CCA percentages, with the 20% CCA showing the highest workability time
- Thermal conductivity was reduced when up to 10% CCA was introduced to the cement mixture. This in turn can enhance insulation properties of the mortar for building construction

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