Application of Corn Husk Ash as Partial Replacement for Cement in the Production of Interlocking Paving Stones

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Abstract

As a way of converting agro-wastes into useful materials for the construction industry, this research considered the application of corn husk ash (CHA) as partial replacement for ordinary Portland cement (OPC) in the production of interlocking paving stones. The study investigated the oxide composition of CHA to ascertain its suitability as a pozzolanic material. Some properties of paving stones with CHA as a replacement for OPC were evaluated. The results showed that CHA is a good pozzolana having satisfied the required standards. The compressive strength of the specimens, with replacement levels ranging from 5 to 25% cured for periods of 3–56 days, was lower at early curing age but improved significantly at later age. Five percent (5%) replacement level showed increased strength compared to 0% CHA regardless of curing age. Density decreased with increasing CHA content, water absorption increased with CHA content, while abrasion resistance decreased with CHA substitution. The test results revealed that CHA paving stones at 5% replacement can attain higher strength than the conventional ones at longer curing periods due to its pozzolanic characteristics.

Keywords: Corn husk ash (CHA), Pozzolana, Cement, Oxide composition, Interlocking paving stones.

Introduction

Production of cement is one of the major sources of carbon dioxide emission to the atmosphere. CO₂, which is a greenhouse gas, contributing about 65% of global warming (Vijayakumar *et al.*, 2013). The high energy demand as well as the emission of carbon dioxide, which caused global warming and depletion of limestone deposits are the major problems associated with cement production (Manasseh, 2010). Badur and Chaudhary (2008) stated that about seven percent of carbon dioxide is released into the atmosphere, and this has negative effects on the ecology and future of human being as a result of global warming. In addition, cement is very expensive in many developing countries like Nigeria and its usage cannot be sustained. The need for affordable building materials in providing adequate housing for the teeming populace of the world has become the major concern of the researchers. The cost of conventional building materials continue to increase as the majority of the population continues to fall below the poverty line. This thereby necessitates the search for alternative materials as total or partial replacement for cement (Adesanya and Raheem, 2009; Akinwumi and Aidomojie, 2015). The search has led to the discovery of the potentials of using industrial by-products and agricultural residues as cementitious materials.

The application of agro and industrial wastes in cement production is an environmentally friendly ways of dumping of large amounts of materials that would have caused pollution to land, water and air. The agricultural and industrial wastes that possessed pozzolanic properties and which have been studied and applied as partial replacements for cement are rice husk ash (Waswa-Sabuni *et al.*, 2002; Coutinho, 2003; Nehdi, 2003; Bui *et al.*, 2005), corn cob ash (Adesanya, 1996; Adesanya, 2000; Adesanya, 2001; Adesanya and Raheem, 2009), waste burnt clay (Syagga *et al.*, 2001; Shihembetsa *et al.*, 2002), hair fibre (Adedokun *et al.*, 2016), saw dust ash (Udoeyo and Dashibil, 2002; Raheem *et al.*, 2012, Raheem *et al.*, 2017a), corn stalk ash (Raheem *et al.*, 2017b) and corn husk ash (Nazir *et al.*, 2012; Peter and Emmanuel, 2013). The corn husk ash (CHA) which has been proven to be a pozzolanic material was use a partial replacement for ordinary Portland cement (OPC) in this study.

Corn husk is a residue obtained from maize, which is the major cereal crop produced in sub-Saharan Africa. According to the data released by food and agriculture organization (FAO) in the year 2000, 589 million tons of maize were produced all over the world in 2000 (FAO, 2002). FAO further stated that about 20% of the weight of maize is the husk, with the recorded wastes of about 117.8 million tons from world produce in 2000. The USA was the largest producer of maize with about 43% of world production. According to IITA (2002), Africa produced 7% of the world's maize and Nigeria was the second largest producer of maize in Africa after South Africa. Corn husk is a thin cellulose rich leafy sheath that covers the corn cob. It has been utilized for various applications ranging from development of cellulose rich fibers and paper making to wrapping of dough in the preparation of Dokunun (Ahenkora *et al.*, 2012). Nazir *et al.* (2012) and Peter and Emmanuel (2013) noted that corn husk ash (CHA) have silica, alumina and iron oxide which are vital components of the pozzolanas in substantial amounts. According to Kevern and Wang (2010), stabilization of soil blocks with CHA has potentials of curtailing the environmental

pollution, reducing the building cost as well as improving the durability of the soil blocks. Previous studies only examined the impacts of CHA on structural concrete and soil blocks (Nazir *et al.*, 2012; Peter and Emmanuel, 2013). However, studies have not been conducted on the application of corn husk ash as partial replacement for cement in the production of interlocking paving stones.

This study therefore investigated the use of CHA as a partial replacement for ordinary Portland cement in the production of interlocking paving stones. It includes the determination of the oxide composition of the CHA, evaluation of the compressive strength, density, water absorption and the abrasive resistance of the paving stones.

Materials and Methods

Material

The corn husk used for this study was collected from LAUTECH Teaching and Research Farm in Ogbomoso, Oyo State, Nigeria (Fig. 1). The collected sample was burnt into ashes in a steel container at a temperature of about 460°C measured with thermocouple thermometer. The yield calculation was carried out, and the physical and chemical properties of the corn husk ash (CHA) were determined. This ash was analyzed using X-ray Fluorescence Analyser (Model QX 1279) at Lafarge Cement, West Africa Portland Cement Company (WAPCO), Sagamu, Ogun State, Nigeria to determine the chemical composition of the CHA.

The Ordinary Portland cement (Dangote Brand of grade 42.5) used was purchased from a retail shop in Ogbomoso. The stone dust was also bought from a dealer in Ogbomoso, and water was obtained from a borehole close the production site of the interlocking paving stones

Fig. 1. Production of corn husk ash

Preparation of sample

Ordinary Portland cement was replaced with CHA at 5, 10, 15, 20 and 25% by weight of cement, with paving stones without CHA (100% cement) serving as control experiment. The mix ratio used was 1:4 (binder: stone dust) and water to cement ratio of 0.5. The specimens (Fig. 2) were prepared for compressive strength, density and durability (water absorption and abrasion) tests using didalo shape moulds with the total area of 0.0243 m² and total volume of 0.0015 m³ in accordance with British Standards. The specimens were cast and well compacted, with the outside surfaces cleaned. After casting, the specimens were placed in the curing room at temperature ranging from 27 -30°C and relative humidity of not less than 90% for 24 h. Compressive strength and density tests were carried out on each of the specimens after curing periods of 3, 7, 14, 21, 28 and 56 days. Water absorption was conducted by weighing the samples of paving stones after 28 days of curing. The samples were then immersed in water for 24 h and the new weights of each sample measured. The water absorption was determined as the ratio of the difference between the soaked and dry weights of the paving stone to that of the dry weight. The abrasion tests were performed on three samples each by first sun drying the samples for seven days after 28 days curing and later immersed in water for 24 h. The samples were then removed from the curing tank and allowed to drain for about 3 h. This was followed by direct scratching of all the sides of the specimens with ten backward and forward strokes of iron brush. The resulting scratched particles of different samples of the interlocking paving stones were weighed to give the amount of abrasive resistance of each specimen

(a) Paving stone mould

(b) Produced paving stones

(c) Curing of paving stones

Fig. 2. Production and curing of the CHA interlocking paving stone

Results and Discussion

Oxide composition

Table 1 shows the oxide composition of the corn husk ash. The result from the table showed that CHA has combined percentages of silica, alumina and iron oxide of 74.97% which is more than 70%. This is an indication that CHA is a good pozzolanic material in accordance with the requirements in ASTM C 618 (2005). The alumina ratio (AR), silica ratio (SR) and lime saturation factor (LSF) were calculated as shown in equations 1, 2 and 3, respectively. This shows higher silica content and low free lime in the ash. The silica content of CHA (65.25%) is slightly lower than that of corn cob ash with a value of 66.38% (Adesanya and Raheem, 2009).

$$LSF = \frac{CaO}{(2.8SiO_2 + 1.2Al_2O_3 + 0.65Fe_2O_3)} \quad 1$$

$$SR = \frac{SiO_2}{(Al_2O_3 + Fe_2O_3)} \quad 2$$

$$AR = \frac{Al_2O_3}{Fe_2O_3} \quad 3$$

Chemical constituents	Percentage composition (%)			
	Sample 1	Sample 2	Sample 3	Average
SiO ₂	65.06	66.12	64.57	65.25
Al ₂ O ₃	6.65	6.03	5.81	6.16
Fe ₂ O ₃	3.73	2.98	3.96	3.56
CaO	9.28	10.31	9.74	9.78
MgO	1.84	1.48	1.69	1.67
SO ₃	1.02	1.00	1.42	1.15
K ₂ O	0.03	0.03	0.04	0.03
Na ₂ O	4.66	3.35	3.16	3.72
LOI	3.07	3.47	2.45	3.00
LSF	0.05	0.05	0.05	0.05
SR	6.27	7.34	6.61	6.71
AR	1.78	2.02	1.47	1.73
Total SiO ₂ +Al ₂ O ₃ +Fe ₂ O ₃	75.44	75.10	74.34	74.97

LOI = Loss on Ignition, LSF = Lime Saturation Factor, SR = Silica Ratio, AR = Alumina Ratio.

Physical properties

The specific gravity of the corn husk ash was determined as 2.02 which is less than that of cement (3.01).

Fig. 3 shows the grading curve of the CHA which falls within the sand zone of the particle size distribution curve stretching from the fine to coarse divisions. The result indicated that CHA has 55% of particles in the fine sand division. This material falls within zone 2 of the grading curve according to Elinwa and Ejeh (2004).

Fig. 3. Particle size distribution curve for corn husk ash

Fig. 4 shows the results of the sieve analysis for the quarry stone dust used for the production of the interlocking paving stone. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) obtained from the figure in accordance with BS 1377 (1990) were 3.95 and 0.96, respectively. Thus, the quarry dust can be said to be between the zone of fine sand and fine gravel, which makes the material a suitable material for the production of good interlocking paving stones (Smith and Smith, 1998).

Fig. 4. Particle size distribution curve for quarry stone dust

Density

The effects of CHA replacement on the density of the interlocking paving stone at different curing periods is presented in Fig. 5. Results showed that the density of the CHA interlocking stones generally decreased with curing age and the decrease became insignificant after 28 days curing periods. At 7 days curing, density decreased slightly with CHA substitution from 0 to 20%; however it significantly decreased to the lowest value at 25% CHA substitution. Results at 14 days showed a similar trend to those of 7 days curing period. At 28 days curing, density decreased slightly with increasing amount of CHA from 0 to 25% replacements. Generally, these results showed that density decreased with both curing days and increased contents of CHA substitutions, which is also in agreement with previous studies by Raheem *et al.* (2017a&b)

Fig. 5. Effects of the CHA on the density of the interlocking paving stone observed at 5% replacement.

Compressive Strength

The effect of CHA on the compressive strength of interlocking paving stone is presented in Figure 6. The results from the figure indicate that compressive strength generally increased with curing period but decreased with increasing amount of CHA except that of the 5% addition.

The result at 3 days showed lower compressive strengths for the CHA interlocking paving stones when compared with that of the control except for 5% CHA substitution, which was higher than the control. The strength decreased with increasing contents of corn husk ash, from 3.50 N/mm² for 5% CHA replacement to 2.20 N/mm² for 25% replacement. The highest compressive strength was observed at 5% replacement of OPC with CHA.

At 7 days of curing, similar trend was observed but with higher strength than those of 3 days curing periods. This showed that compressive strength increased with curing days, due to hydration process. The results at 14 days of curing were much higher than those of 7 days curing, with highest strength observed from sample with 5% CHA replacement. Results showed an increase in strength from 3.77 N/mm² for the control to 5.28 N/mm² for 5% CHA substitution. The results obtained from the 10-15% CHA samples were higher than that of the control while those of the 20-25% CHA replacements were lower. This shows that concrete containing CHA gain strength slowly at early age of curing, which is in line with previous findings by Hossain (2005), Adesanya and Raheem (2009) and Raheem *et al.* (2012).

At 28 days of curing, the strengths of the CHA interlocking paving stone were lower than that of the control except that of 5% CHA replacement, which showed higher strength. The strengths were slightly higher than that of 14 days. The results at 56 days showed an increase in strength when compared to those of 28 days of curing, and this can be attributed to the pozzolanic activity of CHA.

These results clearly indicate that CHA had significant effects on the compressive strength of the interlocking paving stone, with its effective optimum performance observed at 5% replacement.

Fig. 6. Effects of the CHA on the compressive strength of the interlocking paving stone

Water Absorption

Fig. 7 shows the effects of CHA percentage replacement on the water absorption of the interlocking paving stone. The figure revealed that water absorption increased with increasing amount of corn husk ash, with the values ranging from 5.16% for the control to 9.44% for 25% CHA substitution. This indicates that the affinity of the interlocking stone for water increase with an increasing amount of the CHA, which maybe as a result of the increasing content of silica. This is also in agreement with previous findings that higher contents of the CHA in concrete increased its affinity for water (Udoeyo *et al.*, 2006; Sashidhar and Rao, 2010; Chowdhury *et al.*, 2015).

Fig. 7. Effects of the CHA on the water absorption of the interlocking paving stone

Abrasion

Fig. 8 shows the effects of CHA substitution on the abrasion resistance of the interlocking paving stone. Results from the figure indicated that the abrasion value of the paving stone increased with percentage increase in the amount of replacement of ordinary Portland cement with corn husk ash. It was observed that the interlocking stone made with 10% and 25% CHA substitutions gave highest abrasion value and thus undergone the highest shrinkage. However, the specimen with 0% and other CHA replacements showed the lowest shrinkage values, indicating the highest resistance to abrasion.

Fig. 8. Effects of the CHA on the abrasion resistance of the interlocking paving stone

Conclusion

Based on the results of various experimental tests conducted on the CHA interlocking paving stones, the following conclusions can be drawn for the study.

- (i) Corn husk ash (CHA) is a good pozzolanic material, since it has the combined percentage composition of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) of 74.97%.
- (ii) The compressive strength of the interlocking paving stones increased slightly with curing period and amount of CHA at early curing age, but the strength improved significantly at the later curing period especially under 5% CHA addition, indicating pozzolanic reaction. Results indicate that only 5% CHA replacement is adequate to enjoy maximum benefit of strength gain.
- (iii) The water absorption of the CHA interlocking paving stone increased with increasing amount of corn husk ash. The abrasion of interlocking stones increased with addition of CHA, indicating a decrease in the resistance to abrasion of the paving stones. The density of the paving stones decreased with CHA and curing periods.
- (iv) Interlocking paving stones made with 5% CHA replacement is therefore recommended for use in the building because of its higher strength as compared to the control, which contains 100% ordinary Portland cement. This recommended CHA replacement can be used in residential landscaping, especially in residential drive ways, walk ways and pedestrian walk ways on highways.

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