Enhancing the Properties of Soil Bricks by Stabilizing with Corn Husk Ash

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Abstract

A study was conducted to investigate the potential of corn husk ash as an enhancer for the production of soil blocks for low cost housing. Five different levels of stabilisation (0%, 5%, 10%, 15% and 20%) using corn husk ash were adopted for this study. Fifteen blocks were moulded for each stabilisation level. In all a total of 75 blocks were moulded and subjected to the compressive strength, abrasion resistance and water absorption by capillarity tests after curing for 28 days and compared with the relevant standards of compressive earth blocks. In general, there was a significant improvement in the compressive strength characteristics of the stabilized soil blocks. From the compressive strength test results, compressive strengths of 4.177MPa, 4.380MPa and 4.053MPa were obtained for blocks admixed with 0%, 5% and 10% corn husk ash respectively. Soil blocks mixed with 20% corn husk ash had the highest compressive strength of 5.311MPa followed by blocks which had 15% corn husk ash addition also with a compressive strength of 4.917MPa. The water exclusion and the abrasion resistance properties also showed significant improvement as the quantity of corn husk ash increases. There was a significantly strong negative correlation of 0.754 existed between the abrasion coefficients and the water absorption coefficients of the soil blocks. Stabilizing of soil with corn husk ash can improve the properties of soil and soil blocks making the suitable for use as a building material for the construction of load bearing walls.

Keywords: Corn husk ash, Soil stabilised brick, Abrasion resistance, Water absorption by capillarity, Compressive strength

1. Introduction

Housing over the years has been regarded as one of the most important needs of man and as such the demand for it is always on the increase. This increasing demand for housing has been a major problem facing governments in most developing countries around the globe. Ghana's housing deficit stood at about 300,000 and it was estimated that about 1.2 million new housing units were needed by the year 2005. This indicates that over 133,000 new housing units are expected to be delivered annually to meet the target. However, only 25,000 units were produced leaving an unsatisfied annual demand of 108,000 units. As a result, shift dwelling units such as kiosks, tents, cargo containers, served as homes for 1.9% of the population, besides the 3% who are homeless (Mahama & Antwi 2006; GSS 2012). A current study of the affordable housing initiated by governments over the years in Ghana have had marginal impact as the low-income earners who form the majority of the population lack the financial muscle to have access to some of these decent and affordable housing facilities.

As evident in most developing countries, it is almost impossible to fulfil the immense requirements for shelter neither with conventional construction techniques, nor with conventional building materials i.e. concrete, aluminium and steel which are noted for their high energy consumption during production and associated negative environmental impacts (Minke 2006). In Ghana, most buildings are constructed with cement blocks, burnt-clay blocks, timber, and concrete which could be afforded by relatively few due to their high cost. As a way of ensuring a sustainable environment and efficient use of resources, there has been the promotion of building materials from locally available natural and renewable materials. One of these options is the replacement of cement blocks and blocks with soil blocks. Soil has been one of the major building materials in Ghana since pre-colonial days and is readily available with low procurement cost.

The main drawbacks of using soil block as a building material is the need for continuous maintenance due to its low durability and poor resistance to water (Adam & Agip 2001). Soil blocks have also been found to suffer from shrinkage cracking and most importantly low strength making them unsuitable for homes of more than two-storeys high. This has led to the stabilization of soil blocks with cement, lime, bitumen so as to improve its properties (Kamang 1998) even though most of these stabilisers are costly and unsustainable.

Stabilization of soil is the process of modifying the soil properties in relation to its strength, texture, voids and water resisting properties, so as to obtain permanent properties compatible with a particular application. Rigassi (1985) reiterated that, stabilizing soil leads to irreversible change in the physical properties of soil depending on the quality of building design, materials employed, economic aspects of the project, or on issues of durability. The use and adoption of the right stabilisation method can improve the compressive strength of a soil by as much as 400% to 500% with other supplementary characteristics such as increased cohesion, reduced permeability, improved water repellent, increased durability and minimal shrinkage and expansion of soil during dry and wet conditions (Adam & Agip 2001).

Corn is the largest staple crop as it accounts for 50-60% of total cereals produced in Ghana. It currently has an annual production of 1.7 million metric tons indicating a growth rate of 13.33%, which accounts for more than 4% of the country's agricultural gross domestic product (Halm *et al*. 2004). It is used as human food in the form of tortillas, porridge, popcorn and barbecues and as forage and silage for animals. The corn husk which is the thin cellulose-rich leafy sheath that covers the corn cobs contains high cellulose content and has been exploited for different applications including the development of cellulose-rich fibres, paper making, as solid substrate for citric acid production and for wrapping dough in the preparation of Ga kenkey (Ahenkora *et al*. 2012). In spite of having been associated with so many applications, it is not an uncommon practise to dispose-off corn husks along with corn stalk and leaves either by burning or tilling into the soil in developing countries like Ghana. As a way of ensuring a sustainable environment, researchers are focusing on ways of utilizing industrial and agricultural wastes of which corn husk is an example. Nazir *et al*. (2012) reiterated that the ash of the corn husk is believed to possess substantial amount of siliceous compounds making it a Pozzolanic material. This property makes it feasible to function as a cementitious material by improving the binding forces between the soil particles (Kevern & Wang 2010). On a wider scale, the stabilisation of soil blocks with corn husk ash can also curtail the pollution of the environment, reduce the cost of building whiles most importantly, enhancing the durability of soil blocks. Whilst numerous studies have been conducted on some chemicals and agricultural wastes as stabilisers, the same cannot be said of corn husk ash even though it is one of the major crops cultivated worldwide. Therefore, the object of this study is to determine the compressive strength and durability properties of soil blocks stabilised with corn husk ash.

2. Materials and Methodology

2.1 Natural Soil Used

The soil used was sourced from the campus of Takoradi Polytechnic. The top soil which harboured plants matter was first scraped-off before the samples were dug as excessive plants matter could hamper the properties of soil blocks (Maniatidis & Walker, 2003). The soil sample was then sieved through a 19mm sieve mesh before the grading test was conducted which is presented in Figure 1. The characteristics and qualities of the natural soil are also presented in Table 1 and Figure 2. The Optimum moisture contents (OMC) and the Maximum dry densities of each level of stabilisation as presented in Table 2 were determined through the Standard Proctor's Test.

2.2 Corn Husk Ash

The corn husk used was sourced from Ejura which is 106km from Kumasi, the regional capital of the Ashanti region, which lies within the geographical coordinates of 7.3833°N and 1.3667°W notable for the cultivation of corn in Ghana. The corn husk for the purpose of this study refers to the dry outer covering of the corn kernel which is left behind after harvesting. The corn husks were gathered on the farm and subjected to uncontrolled combustion in the open amidst constant stirring the husks to ensure even combustion. In other words, the incineration conditions of the corn husk ash were not controlled in this study. It was then allowed to cool naturally before packing into sacks. The packed corn ashes were then transported to Takoradi where it was sieved using a 325 mesh before determining the chemical composition at the Ghana Standard Authority using the Gravimetric method with focus on its Pozzolanic properties which is shown in Table 3.

2.3 Water

Drinkable tap water devoid of contaminants was used in this study.

2.4 Preparation of Soil Bricks

The soil and corn husk ash were thoroughly mixed with spade and compacted manually. With five different batches (0%, 5%, 10%, 15%, and 20%), 15 soil blocks with nominal dimensions 200mm × 150mm × 100mm were produced from each batch. The soil blocks were initially covered with damp plastic sheets and sacs for the first 7 days which [10] averred that it was essential as this prevent surface shrinkage cracking due to rapid evaporation which tends to promotes undesirable loss and uneven distribution of moisture in the blocks. The sheets were then removed after which the soil blocks were air dried at room temperature for the remaining 21 curing days as shown in Figure 2 and Figure 3. Laboratory tests were conducted on the soil blocks to evaluate their compressive strength, water absorption and abrasion resistance properties.

Figure 1. Moulded Soil bricks

Figure 2. Curing of bricks using Plastic sheets

3. Experimental Results and Discussions

3.1 Properties of Natural and Stabilized Soil Samples

Table 1. Characteristics of the Natural soil before Stabilizing with Corn Husk Ash

Property	Result
Colour	Reddish-brown
Soil description	Well-graded gravel-sand mixture with little or no fines
Natural moisture content	6.2%
Organic matter content	5.3%
Specify gravity	2.86
Free swell index	42.9%
Shrinkage limit	12.2%
D_{10}	0.24mm
D_{30}	2.90mm
D_{60}	5.50mm
Clay content	10.5%
Silt content	21.1%
Sand and Gravel content	68.4%
Liquid limit	58.7%
Plastic limit	27.3%
Plasticity index	30.70%
Optimum moisture content	12.3%

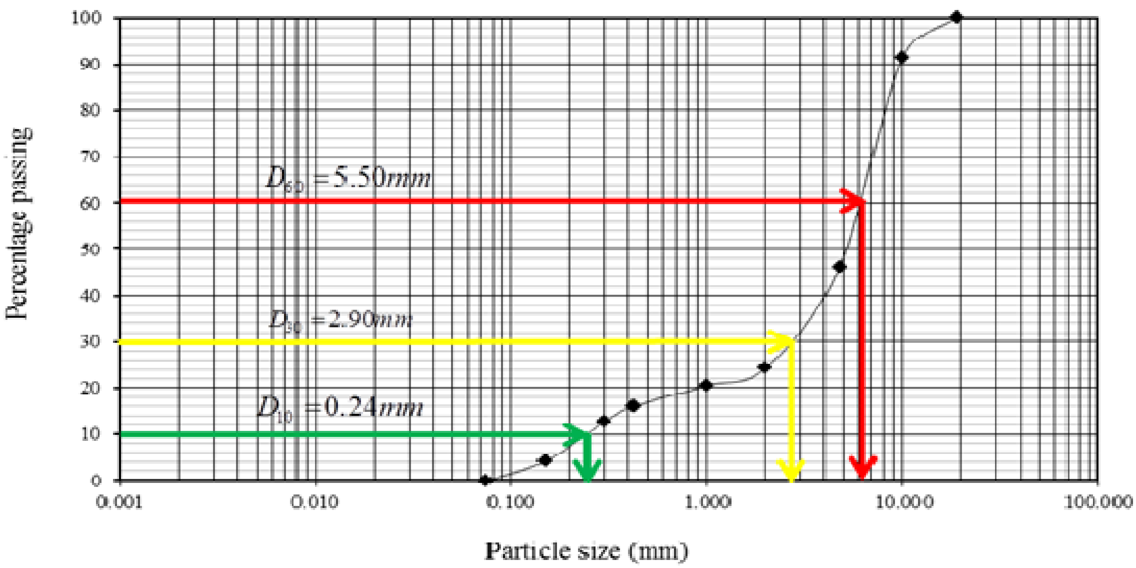

Figure 3. Particle size characteristics of Natural soil sample

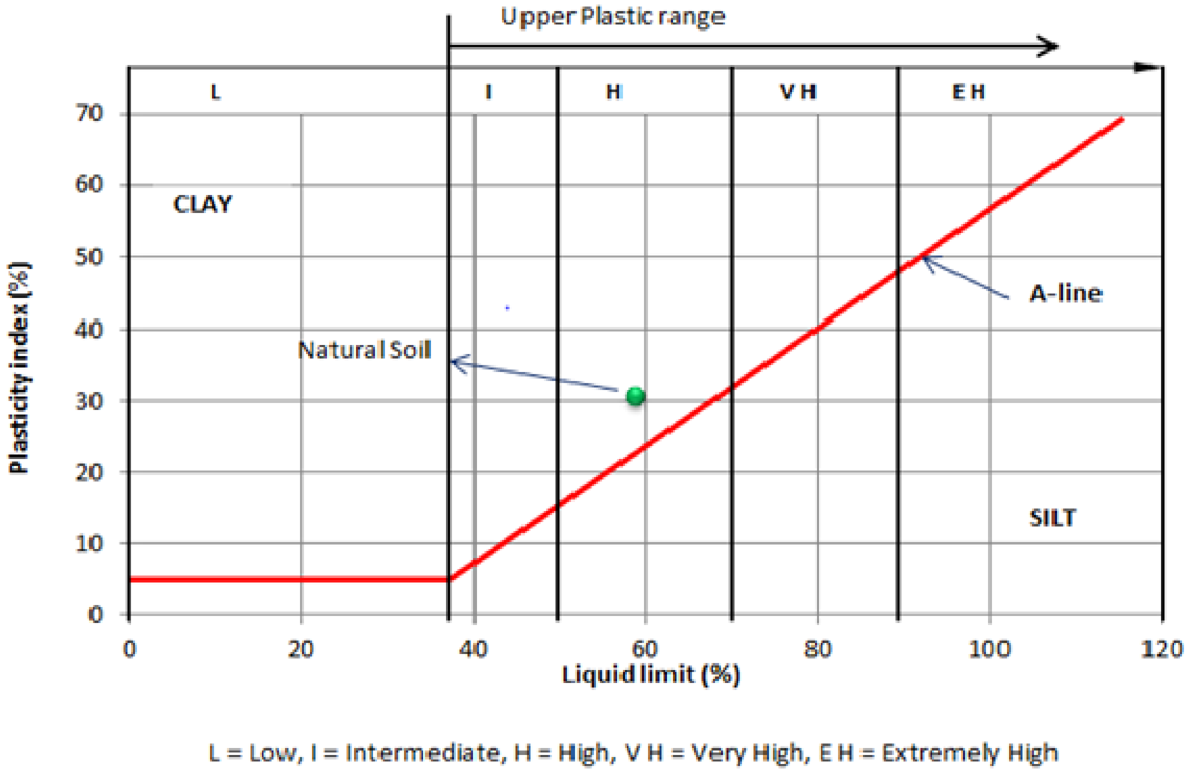

Figure 4. Plasticity Chart of Natural soil sample

Table 2. Properties of the Natural and Stabilised soils

Property	Corn husk Ash				
	0%	**5%**	**10%**	**15%**	**20%**
Maximum dry density (kg/m^3)	1950.00	2020.00	2000.00	1980.00	1920.00
Optimum moisture content (%)	12.30	12.40	13.20	13.00	12.40
Plastic limit (%)	28	26.2	27	25.2	26.5
Liquid limit (%)	58.70	56.80	55.03	51.70	51.20
Plasticity index (%)	30.70	30.60	28.03	26.50	24.7
Shrinkage limit (%)	12.20	12.20	11.10	6.70	4.44

Generally, the results of the compaction tests and Atterberg tests on the soil agreed with an earlier study conducted on agricultural wastes by Mtallib *et al*. (2011) and Oluremi *et al*. (2012) but differ in details. It was established that the highest maximum dry density was reached after 5% addition of corn husk ash to the soil whiles the highest optimum moisture content was found after 10% corn husk ash addition to the soil before declining. Comparatively, the high liquid limit and plasticity index of the natural soil saw a gradual decline as the quantity of the corn husk ash increased.

The general decrease in the liquid limits and plasticity indices of the soil are attributed to the additions of the corn husk ash which reduce the amount of the clay particles in the soil that can freely allow water molecules to enter between the layers causing expansion or shrinkage. The decline in the plasticity index of the soil corroborates the fact that stabilising soil with corn husk ash improves its use as a construction material.

3.2 Chemical properties of the Corn husk ash

The percentage of corn ash retained on a 325 mesh was 12.5% indicating its ultra-fine nature and suitability as filler.

Table 3. Composition of Oxides in the Corn husk ash

Oxides	**Quantity present (%)**
Silica Content as SiO_2	7.4
Magnesium as MgO	1.20
Aluminium as Al_2O_3	2.39
Phosphorus as P_2O_5	2.70
Calcium as CaO	0.60
Iron as Fe_2O_3	1.26
Sodium as Na_2O	0.05
Potassium as K_2O	36.16

The quantities of silica, aluminium and iron oxides present in the corn husk ash were found to be 7.4%, 2.39%, 1.26%, respectively which when summed was below the minimum requirement range of 50% - 70% (!SG n/d) for the different classes of Pozzolans whiles there were high levels of potassium. The relatively high potassium content found in the corn husk ash was attributed to the Potassium-based fertilizer mostly used in the area for the cultivation of corn. The presence of the oxides in such small quantities could be attributed to the uncontrolled nature of combustion in the open resulting in high level of unburned matter which contradict an earlier study by (ASTM 2004) who posited that open-air combustion of agricultural wastes in heaps results in ashes that exhibits high Pozzolanic activities.

3.3 Compressive Strengths of Soil Bricks

The compressive strengths of the soil blocks were determined after 28 days curing age. Five soil blocks with minimal cracks were randomly selected from each batch and crushed using ADR 2000 Compressive Strenght Machine. The results of the test are presented in Table 4 below.

Table 4. Anova summary of Compressive strength of Soil bricks after 28 days curing age

Batches	**Mean Compressive Strength**	**SD**	**F-value**	**P-value**
Soil + 0% Corn ash (Control group)	4.177	0.144	23.414	0.000
Soil + 5% Corn ash	4.380	0.119		
Soil + 10% Corn ash	4.053	0.249		
Soil + 15% Corn ash	4.917	0.132		
Soil + 20% Corn ash	5.311	0.258		

From Table 4, the F-value obtained after performing a one-factor ANOVA test to a significance level of 5% illustrates a high variability between the different levels of stabilisation than within the batches attributing it to the effects of the corn husk ash. Even though, all the soil blocks produced were suitable for the construction of load bearing walls of one and two storeys which according to (Martirena *et al*. 1998) should have a minimum compressive strength of 1.4 N/mm^2 and 2.8N/mm^2 respectively. There was a general increase in the compressive strengths of soil blocks as the quantities of stabiliser increased. Soil blocks with no stabilisation (control group) had an average compressive strength of 4.177N/mm^2 whiles the compressive strength of blocks with 5% addition of corn husk ash was 4.9% higher than those of the control group. Slightly diverging, from the trend were soil blocks stabilized with 10% corn ash with an average compressive strength being 2.97% lower than those without stabilizer (control group). This decline was attributed to the numerous gravel particles found in the blocks after the test which inhibits bonding. Soil blocks with 15% and 20% corn husk ash had their compressive strengths being 17.72% and 27.2% respectively better than soil blocks with no corn husk ash (control group).

It was found that increasing the corn husk ash in the soil blocks improved the compressive strengths as there is an increase in the formation of compounds possessing cementitious properties that binds with the particles together. This according to earlier studies (Ogunbode & Apeh 2012; Olaoye & Anigbogu n/d) occurs predominately due to the presence of silica and other crucial compounds present in the corn husk ash and the natural soil confirming studies conducted on Pozzolanic and stabilising materials.

3.4 Abrasion Resistance of Soil Bricks

As an important criterion of soil blocks, the abrasion coefficient according to [4] is deduced through Equation 1.

$$C_a(cm^2/g) = \frac{S}{M_1 - M_2} \qquad (1)$$

The abrasion coefficient (C_a) expresses the ratio of the brushed surface S (in cm^2) to the mass of the material detached by the brushing ($M_1 - M_2$, in grams).

Table 5. Anova summary of *Abrasion Coefficients of Soil blocks after 28 days curing age*

Batches	Mean Coefficient of Abrasion (cm^2/g)	SD	F-value	P-value
Soil + 0% Corn ash (Control group)	0.407	0.041	27.064	0.001
Soil + 5% Corn ash	0.557	0.040		
Soil + 10% Corn ash	0.661	0.135		
Soil + 15% Corn ash	0.816	0.000		
Soil + 20% Corn ash	1.823	0.393		

From Table 5, there was a high variability between the different levels of stabilisation than within the batches shown by an F-value of 27.064 indicating the effects of the corn husk ash on the soil blocks. From the results, the soil blocks showed a steady improvement in their resistance to abrasion (wear) as the dosages of stabilizer were increased. Whiles blocks without stabilizers had the least resistance to abrasion with a coefficient of $0.407cm^2/g$, those with 20% stabilizers had the highest resistance with a coefficient of $1.823cm^2/g$.

Comparatively, the abrasion resistance of soil blocks stabilised with 5% corn husk ash was found to be 36.9% better than soil blocks with no ash. Increasing the content of the corn husk ash to 10% saw a further improvement as its resistance was 62.5% better than those without corn husk ash. Soil blocks stabilised with 15% and 20% corn husk blend had their resistances to wear being 100.7% and 348.4% better than soil blocks with no corn husk ash. The increase in abrasion coefficients of the soil blocks as the corn husk ash increase is attributed to the improved cementitious action between the corn husk ash and that of the soil resulting in an enhanced bond strength which holds the particles in a matrix.

3.5 Water Absorption by Capillarity rise of Soil Bricks

This test was conducted by partially immersing the soil blocks in water for 10 minutes. The absorption coefficient as indicated by Adam and Agip (2001) depends on the speed of absorption and deduced from the Equation 2.

$$C_b(g/cm^2min) = \frac{M_1 - M_2}{s\sqrt{t}}$$

Where;

$M_1 - M_2$ = Mass of water, in grams, absorbed by the block during the test (g),

s = Surface area of the submerged face, in square centimetres (cm^2), and

t = Duration of time of the immersion of the block, in minutes (min)

Table 5. Anova summary of *Abrasion Coefficients of Soil blocks after 28 days curing age*

Batches	**Mean Coefficient of Water Absorption (g/cm^2 min)**	**SD**	**F-value**	**P-value**
Soil + 0% Corn ash (Control group)	46.35	5.450	109.63	0.001
Soil + 5% Corn ash	32.59	2.694		
Soil + 10% Corn ash	19.64	2.112		
Soil + 15% Corn ash	9.12	1.014		
Soil + 20% Corn ash	2.65	0.575		

All the soil blocks studied absorbed water by capillarity. The total water absorbed by the soil blocks gradually declined as the quantity of corn husk ash increased with soil blocks with 20% addition having the least water absorption coefficient (2.65g/cm^{2}min) whiles blocks without corn husk ash (control group) recording the highest water absorption coefficient (46.35g/cm^{2}min) supporting an earlier study by Maniatidis and Walker (2003) that, the amount of stabilisers influences the water absorption properties of soil bricks.

The decrease in permeability is as a result of the reduction of pore spaces as the finer particles of the corn husk ash fill the voids thereby drastically reducing the flow of water within the soil blocks or could be attributed to the increase in the pH value of the moulding water as a result of the partial dissociation of the calcium hydroxide (Okunade 2008). These calcium ions (Ca^+) combine with the reactive silica or alumina or at worst both, present in the soil to form insoluble calcium silicates or aluminates or both which inhibits the passage of water through the soil blocks.

4. Conclusion

Particle size distribution curve of the soil used in this study was well-graded gravels, gravel-sand mixture with little or no fines and suitable for the production of soil blocks. Even though, the corn husk ash used in the study did not qualify to be a Pozzolana as the vital components of most Pozzolana compounds (SiO_2, Al_2O_3 and Fe_2O_3) were available in small quantities, it was able to improve the engineering properties of the natural soil and the soil blocks.

Stabilisation of soil with corn husk ash significantly improved the compressive strength of soil blocks although blocks produced were suitable as masonry wall units. Generally, increasing the quantity of corn husk ash increased the compressive strengths of the soil blocks. The soil blocks generally showed a remarkable improvement in their durability properties (abrasion and water absorption by capillarity). As the quantity of corn husk ash in the soil blocks increased the ability of the soil blocks to resist abrasion also increased appreciably. Furthermore, soil blocks also tend to have high water exclusion property as the quantity of corn husk ash increases making it suitable as a masonry wall unit.

As evident in this research, stabilization with corn husk ash can improve the properties of masonry soil blocks that can effectively replace the conventional masonry units which are noted for their negative environmental impacts.

5. Limitations and Way Forward

In spite of the numerous findings, a number of possible limitations needs to the highlighted. First the study used corn husk ash which was burnt without controlling the combustion temperature. This limited thorough understanding of the effects of temperature on the characteristics of the ash. Since, soil vary extensively even in a given locality, this research is also confined to the locality where the soil was sourced. As a way of improving the study it is recommended to source the materials from different areas and also vary the combustion temperature of the corn husk ash.

Acknowledgement

Special thanks to the technical staff of the Civil engineering laboratory at the Takoradi Polytechnic for their contribution and insight during the study.

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