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Original Article

Effects of Shea Nutshell Ash on Physical Properties of Lateritic Soil

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Abstract - *This study focused on examining the effects of Shea nutshell ash (SNSA), derived from the calcination of Shea nutshell (an agro-based waste) as a partial replacement for cement on the stabilization of lateritic soils for the production of interlocking earth blocks. The optimum percentage of cement to stabilize the lateritic soil was partially replaced by SNSA from 0 to 6% by mass with a step of 2. The effects of SNSA on Atterberg limits, maximum dry density and optimum moisture content of Lateritic Soil were evaluated. The results showed that the shrinkage decreased by 12.6 % with increasing SNSA content and the plasticity index decreased by 8.43 % up to 4 % of SNSA before increasing with 6% of SNSA. The maximum dry density and optimum moisture content increased by 11.62 % and 3.16 %, respectively with increasing SNSA content. Based on these results, stabilization of lateritic soil with SNSA, in addition to being affordable and environmentally friendly, improved the physical properties of the soil for use in construction works*.

Keywords - *Shea nutshell ash, lateritic soil, Atterberg limits, maximum dry density, optimal moisture content.*

I. INTRODUCTION

The right to adequate housing has been recognized as an integral part of the right to an adequate standard of living in the Universal Declaration of Human Rights of 1948 and the International Covenant on Economic, Social and Cultural Rights of 1966. Elias & Omojola (2015) [1] found in their study that in Africa, due to the high costs of housing construction, about 75% of low and middle income people do not have access to adequate housing with reasonable sanitation standards. The UN-Habitat (2014) [2] states that 60% of urban residents in Africa live in slums and unplanned settlements. According to UN-Habitat (2008) [3], 4,000 new housing alternatives are needed every hour by a growing population of poor people.

However, in developing countries, it is difficult or impossible to guarantee these rights because sustainable building materials are expensive. Therefore, people resign themselves to use the earth for brick making to protect themselves from the weather. Unfortunately, these types of construction do not last and collapse more often during heavy rains, sometimes resulting in loss of life. This is because these blocks are not stabilized. For this reason, several methods are available to people wishing to use these types of construction to enable them to stabilize these blocks, mainly the addition of cement or lime [4], [5]. However, these stabilization materials are expensive and not affordable for the extremely poor population of developing countries and furthermore they are not environmentally friendly and contribute to the destruction of the environment due to the CO_2 emissions generated in their production. Ekinci et al. (2020) [6] reported in their study that cement production is one of the main sources of environmental pollution in the world due to CO_2 emission: about one ton of CO_2 is released into the environment for every ton of cement produced. There is therefore a need to find new technologies that would use local supplementary cementitious materials (SCMs) through research to facilitate the stabilization of earthen blocks. Thus, an attempt is made in this paper to study the effect of Shea nutshell ash as a partial replacement of cement on Atterberg limits, maximum dry density and optimum moisture content in lateritic soil stabilization.

Shea nutshell ash (SNSA) is an agricultural by-product derived from the burning of the shea nutshell, which is the shell containing the nut from the shea tree fruit. The shea tree, with its scientific name "Vitellaria paradoxa" or "Vitellaria nilotica", also known as the "butter tree" or "women's gold", is a tree that grows exclusively in Africa, particularly in the savannahs of West and Central Africa and in some parts of East Africa. There are two known subspecies of shea, Vitellaria ssp. paradoxa which predominates in West Africa and ssp. nilotica which is found in Central and East Africa - the former generally having a higher stearin content than the latter [7]. In recent times, due to its value and varied uses, including cosmetics, pharmaceuticals and nutrition, it has received increasing attention. All parts of the tree are used: the fruit is eaten, the leaves are eaten in sauces, the wood is used as firewood, the bark can be used in herbal teas for pharmaceutical purposes (to treat dysentery or bilharzia), and the kernels are processed into edible or cosmetic products. The most important commercial use is the processing of the nuts into shea butter, which is used for cooking, as medicine and as a cosmetic ingredient. The shell is used as an exfoliating powder for facials. Traditionally, the shell is used to compact areas of stagnant water. In order to double the benefits of the butter and to preserve the environment, the use of shea nutshells as fuel has been proposed[8].

The modern use of SNSA is specifically based catalyst for the production of ethanoic biodiesel [9]. In construction work, SNSA has been used as a partial replacement of cement in mortar [10] and as a partial replacement of cement for sustainable and affordable concrete production [11]. The results of these studies showed that SNSA is a suitable material for use as a pozzolan. Setting times increase with the increase of the cement replacement and compressive strength generally increases with the increase of curing period and decreases with the increase of SNSA content. Although there are possibilities of using SNSA in concrete and mortar proven by these previous studies, there is a lack of information regarding its use in soil stabilization. Therefore, the present study focused on SNSA's effects on Atterberg limits, maximum dry density and optimum moisture content of lateritic soil for making earth blocks.

II. MATERIALS AND METHODS

A. Materials

This study was conducted at the Civil Engineering Laboratory of Jomo Kenyatta University of Agriculture and Technology (located in Juja, Kenya) and the materials used included lateritic soil, shea nutshell and cement.

a) Lateritic soil: The lateritic soil used in this study was obtained locally from the farm of Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. The soil was sourced at a depth of 600mm below the earth in order to avoid inclusion of humus material. The lateritic soil was sieved through sieves of size 5 mm and used, while disposing what was retained on the sieves.

b) Shea nutshell: The Shea nutshell is the envelope containing the Shea nut from the fruit of this tree (Shea) which grows naturally in the savannahs of Africa. The Shea nutshells (Figure 1) were collected from the northern region of Uganda.

Figure 1: **Shea nutshells**

c) Cement: The cement used was CEM IV/32.5R pozzolanic cement that complies with the current Kenyan standards [12]. It was purchased from suppliers in Juja, Kenya.

d) Water: In this study, potable water used to mix the different materials was sourced from the JKUAT water supply system, which complies with the Kenyan water regulations [13].

B. Methods

a) Shea nutshell ash: The Shea nutshells, once obtained, were sorted to remove other waste materials and then subjected to open burning to decarbonize the shells (Figure 2(a)). They were then ground and sieved through a 0.3 mm sieve before being calcined at 650°C to obtain the ash (Figure 2(b)). The ash was analyzed for its chemical properties as recommended by ASTM C 618 (1990) [14] at the Ministry of Mines laboratory in the Nairobi Industrial Estate. X-ray fluorescence (XRF) process was used to analyze the major chemical elements present in the ash (Si, Ti, Al, Fe, Mn, Mg, Ca, K, and P) (Table 1).

(a) Open air burning of Nutshell (b) Sieved SNSA

Figure 2: **Calcination of Shea Nutshells**

Table 1: Chemical composition of Shea nutshell ash

Chemical oxide	Symbol	Results (%)
Calcium calcite	CaO	15.185
Silica	SiO_2	46.548
Aluminium Alumina	Al_2O_3	13.39
Iron iron oxide	Fe_2O_3	3.629
Magnesia magnesium oxide	MgO	7.502
Potassium	K_2O	8.279
Phosphorus pentoxide	P_2O_5	3.395
Nitric oxide	NO	0.002

b) Characterisation of the lateritic soil

Various tests were carried out in order to obtain the physical properties of the lateritic soil; Atterberg limits, particle size distribution, specific gravity, moisture content and soil compaction tests were conducted in accordance with the BS 1377 (1990) [15].

III. RESULTS AND DISCUSSION

A. Physical properties of the soil

a) Particle size distribution: Based on the particle size ranges, the cumulative percentages of mass passing the sieves were plotted on a logarithmic graph to obtain the particles size distribution of the soil (Figure 3). The American Society for Testing and Materials (ASTM) particle classification of the soil is shown in the Table 2. The soil was composed of 75% gravel, 18% sand and 7% silt with a uniformity coefficient of 14 and a curvature coefficient of 1.79, which is thus classified as silty sandy Gravel. The lateritic soil used in this research had a dry density of 1729 kg/m^3. Most researchers found that soil suitable for compressed stabilized soil blocks should have a dry density in the range of 1500 to 2000 kg/m^3 or 1700 to 2200 kg/m^3 [16], [17]. Thus, the density of the soil lies within these ranges.

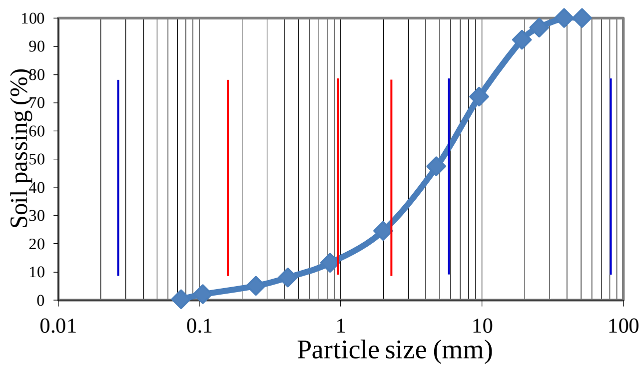

Figure 3: **Particle sizes distribution curve of lateritic soil.**

The lateritic soil had a LL of 42.6% which lied in the range of 25 and 46% recommended by ARSO (2018) [17]. Moses et al. (2020) [18] reported in their study that soils with a plasticity index (PI) value of less than 35.0 could be considered as cohesive grades, capable of being compacted, and able to acquire the necessary compressive strength, and having a reasonable durability characteristic. Then the PI of the soil studied, which is 25.85%, meets this condition. This value is also in the range of 2-30 % recommended by ARSO (2018) [17]. For the soil studied, the linear shrinkage value was 12.71%. It was found that a higher shrinkage limit is not desirable in the manufacture of bricks, as it can create cracks in the final products [19]. The basic properties of the lateritic soil are presented in Table 3.

Table 2: ASTM soil classification

Pebbles	Gravel	Sand	Silt	Clays
200 to 20 mm	20 to 2 mm	2 to 0.06 mm	0.06 to 0.002 mm	0.002 to 0 mm

Table 3: Physical properties of lateritic soil

Property	Value
Proctor test:	
Optimum moisture content (%)	19
Maximum dry density (kg/m^3)	1729
Atterberg limits:	
Liquid limit (%)	42.6
Plastic limit (%)	16.75
Plasticity index (%)	25.85
Linear shrinkage (%)	12.71
Soil classification (BS 1377, 1990)	Silty sandy GRAVEL
Particle size distribution :	
Gravel (60-2 mm) (%)	75
Sand (2-0.06 mm) (%)	18
Silt (0.06-0.002 mm) (%)	7
Clay (<0.002 mm) (%)	0

b) Specific gravity of lateritic soil: According to Raychaudhuri (1980) [21], laterites are generally red-brown soils with a moderately high specific gravity ranging from 2.5 to 3.6. The value of specific gravity obtained using BS 1377-2 (1990) was 2.65. This value of specific gravity obtained is within this range. Thus, it can be concluded that the studied soil is a lateritic soil and can be used for block production.

c) Chemical composition of lateritic soil: Formed from the weathering of rocks under high oxidation and leaching conditions, a laterite soil is a tropical soil rich in ferric oxide. According to Kamtchueng et al. (2015) [23], for a soil to be qualified as laterite, silica/sesquioxide ratio (SS) must be between 1.33 and 2 and for true laterite, the ratio should be less than or equal to 1.33. The chemical components of the lateritic soil obtained with the X-ray fluorescence (XRF) test are presented in Table 4. Silica and aluminum are the two most dominant components, representing 58.675% and 18.429% of the analyzed mass, respectively, followed by iron oxide with 15.48%. It was found that the studied soil does not contain a higher percentage of ferric oxide (15.48%) with a silica/sesquioxide ratio (SiO_2)/ (Fe_2O_3+Al_2O_3) of 1.73. The ratio of the studied soil is therefore within this range of 1.33-2. Thus, based on the ferric oxide content and the silica/sesquioxide ratio, it can be confirmed that the soil studied is a lateritic soil but not a true laterite.

Table 4: Chemical composition of lateritic soil

Chemical composition	Proportion (%)
S_iO_2	58.675
Al_2O_3	18.429
Fe2O3	15.48
MnO	3.368
T_iO	1.402
CaO	0.426
K_2O	1.285
P_2O_5	0.028
Cu	0.004
Ba	0.58
Zr	0.149
Nb	0.038
Zn	0.014
Sn	0.03
Ni	0.013
Pb	0.033

d) Effect of cement and SNSA on Atterberg limits: The Atterberg limits were calculated according to BS 1377, part 2 (1990) [24]. The results are summarized in Table 5. It should be noted that after treating the soil with 6% cement, the PI decreased, as did the shrinkage limit. The same results of PI has been observed by [25] On the other hand, there was an increase in the liquid limit from 42.6 to 44.72%. In the case of the partial replacement of cement by SNSA, a decrease in the PI was observed with the increase in the percentage of SNSA. As for the shrinkage limit, it decreased with the increase in the quantity of SNSA. By fixing the cement at 2% and varying the percentage of SNSA, a decrease of the PI was observed until 4% of replacement and then the plastic index increased with 6% of SNSA (Figure 4). The shrinkage limit decreased as the amount of SNSA increased, which led to the conclusion that the SNSA reduces the PI of the soil as well as the shrinkage limit. This observation is therefore in agreement with Tamur & Gandomi (2021) [26] when they used rice husk ash and fly ash for the reinforcement of cohesive soils.

Table 5: Atterberg properties for unsterilized and stabilized soil

Specimen	Liquid limit (LL) (%)	Plastic limit (PL) (%)	Plasticity index (PI) (%)	Linear shrinkage (LS) (%)
Soil	42.6	16.75	25.85	12.71
Soil + 6% C	44.72	30	14.72	12.07
Soil+2%SNSA+4% C	48.8	27.86	20.94	12.36
Soil+4%SNSA+2% C	43.2	26.26	16.94	11.14
Soil+6%SNSA+0% C	42.9	19.6	23.3	10.98
Soil+0%SNSA+2% C	44.1	25.6	18.5	12.54
Soil+2%SNSA+2% C	46.8	29	17.8	11.64
Soil+4%SNSA+2% C	43.2	26.26	16.94	11.14
Soil+6%SNSA+2% C	44.1	23.58	20.52	10.96

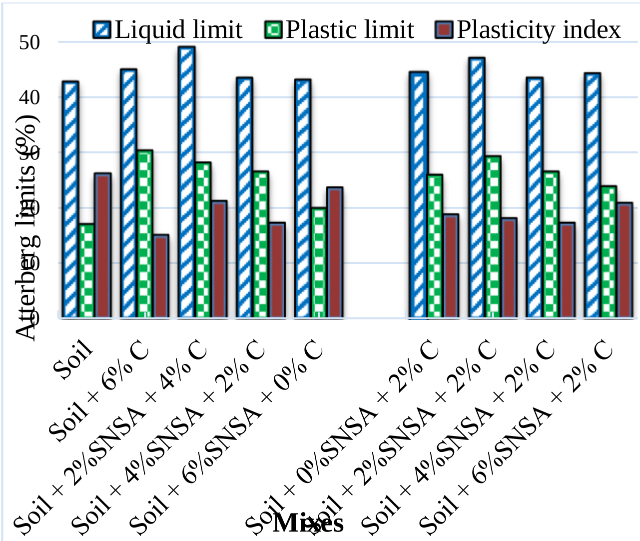

Figure 4: Variation of Atterberg limits for different design mixes of soil-cement-SNSA.

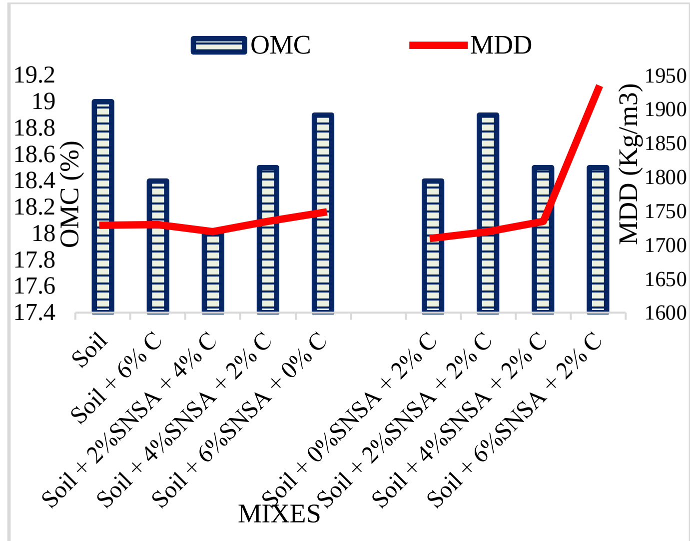

Figure 5: Variation of MDD and OMC for different design mixes of soil-cement-SNSA.

As can been seen from figure 4, adding 2% of SNSA to 4% of cement, led to an increase of the liquid limit, however, a furthered increase beyond this optimum percentage led to reduction of the liquid limit.

The plastic limit of lateritic soil (16.75%) increase by 79.10% on adding 6% of cement. The incremental addition of SNSA from 2% to 6% while reducing the content of cement led to reduction of the plastic limit.

e) Effect of cement and SNSA on maximum dried density and optimum moisture content of lateritic soil: Figure 5 shows the results of stabilized lateritic soil compaction tests. It can be seen that the MDD of the stabilized soil with 6% cement is slightly higher than that of the unstabilized soil (1730 kg/m^3 and 1729 kg/m^3, respectively). The addition of cement also reduced the OMC (from 19 to 18.4%). Several researches had attested to the information that adding cement at a certain percentage (optimum 6%) increases the MDD [27], [28]. The MDD results for different levels of SNSA are shown in Figure 5. It can be seen that the MDD increased with increasing SNSA content. This means that the SNSA led to an increase in density. The maximum value of MDD (1930 kg/m^3) was obtained with 6% SNSA and 2% cement. This increase in MDD with increasing SNSA is due to the specific gravity of SNSA, which is high (2.6). On the other hand, the OMC did not change much with the increase of SNSA, which means that the SNSA significantly increases the MDD without affecting much the OMC.

IV. CONCLUSIONS

The following conclusions have been deduced from the results of the above-mentioned experimental work:

(i) The maximum dry density increases with the increase in SNSA content. That is, SNSA causes the increase in density.

(ii) The OMC increases with the increase in SNSA content.

(iii) The shrinkage limit decreases with the increase in SNSA content.

The plasticity index decreases with the increase in SNSA

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