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Evaluation of the Strength Properties of Soil Bricks Produced with Processed African Locust Bean Waste water as Stabiliser

*Zievie[1], P. and Yalley[2], P. P.
[1]Department of Building Technology and Estate Management, Wa Polytechnic, Post Office Box 553, Wa, Ghana,
[2]College of Technology Education, University of Education, Winneba, Ghana

ABSTRACT : *A newly proposed concept of soil bricks as masonry units for low-cost environmentally friendly construction is proposed using agro-based waste water obtained from the processing of the African locust bean into local food condiments. Laboratory test system was designed to perform strength and durability test on four types of soil brick mixed with African locust bean waste water (ALBWW) as replacement of portable water and also as soil stabiliser for bricks production. Tests were conducted on strength and durability properties of the specimens. There was an increase of 66% over unstabilised specimens when the soil was fully mixed with ALBWW. The density of the bricks increased from 2120kg/m^3 for the soil bricks without ALBWW to 2167kg/m^3 when the soil was mixed with ALBWW. The resistance to wear for bricks increased steadily from 6.45cm^2/g for bricks without ALBWW as stabilisation to 9.45cm^2/g for bricks with ALBWW. The presence of ALBWW reduced the amount of water absorbed by the bricks. The study concluded that ALBWW which is an environmental nuisance can be used to replace portable water and also as stabiliser for masonry units in construction. This then implies that effective utilization of ALBWW as soil stabiliser would reduce the cost of relative durable houses for the rural and peri-urban areas in Northern part of Ghana where locust beans are prevalent.*

Keywords: *abrasion resistance, compressive strength locust bean, water absorption,*

I. INTRODUCTION

Building with soil materials is one of the ancient technology which still remains as the cheapest means of providing accommodation needs to a large number of people. Despite popular misconception that soil is a walling material for low income earners, soil-built houses, according to [1] portray cultural diversity and will continue to be a major integral part of modern housing needs. The most tangible proof of this is the continued use and existence of many thousands of new and historic traditional houses such as rammed, cob, wattle and daub, etc, soil-built houses dotted across both developed and developing countries. Using soil for housing projects offers a number of advantages to human life. Firstly, it is eco-friendly due to its low embodied energy content and low environmental impact. This is because soil is locally obtained with minimal transportation costs and used in its natural state; hence no fossil fuel is needed for processing. Secondly, soil-built houses can boast of excellent sustainability credentials and this is combined with good thermal and acoustic properties. It has also been indicated that earth buildings are cost effective, when compared with other materials. (Dobson, 2000; as cited in [2].

Historically, primitive man in his attempt to use soil to provide comfortable shelter, did little more than sticking lumps of wet soil on poles woven closely together. Though in modern times, the traditional methods of erecting soil houses in the past have improved. It has been found that soil-built houses are vulnerable to the hazards of the weather elements causing early development of erosion, cracks and collapse [1]. To address these and many other problems associated with the use of soil, several experimental investigators have studied the stabilising effect of conventional additives such as cement, lime, bitumen and the like on soil to improve strength and durability properties [3].

Even though research findings have shown that small addition of cement, lime, bitumen, etc, in the soil enhances its performance properties, the Ghana Business News [4] reported that the over dependence on these materials for housing is responsible for the continuous increase in housing cost in developing countries, often beyond the means of the poor. The report added that the importation of clinker and gypsum alone for the production of Portland cement, use extensively in Ghana cost the nation not less than 180 million dollars annually. It is in the light of this that the United Nations Habitat [5] advised that, for developing countries to be able to provide affordable housing, they should take cost of imported materials into consideration and develop new technologies that would employ the use of local materials through research. In response to this, some local additives derived from industrial and agricultural sources have been studied as potential substitutes [1], [6], [5] and [7]. However, most published works have focused on pulverized and ash wastes because of their pozzolanic activity towards lime [8] and [9]. 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 [10] and [11]. 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.

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. Research findings indicate 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 [11]. 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 [10]. The stabilisation mechanism may vary widely from the formation of new compounds binding the finer soil particles to coating particle surfaces by the additive to limit the moisture sensitivity. Therefore, a basic understanding of the stabilization mechanisms involved with each additive is required before selecting an effective stabilizer suited for a specific application. Chemical stabilization involves mixing or injecting the soil with chemically active compounds such as Portland cement, lime, fly ash, calcium or sodium chloride or with visco-elastic materials such as bitumen the process of chemical modification or stabilization with calcium-based chemicals, like African locust bean waste water requires a basic understanding of the mechanisms of reaction. Each calcium-based stabilizer contains some amount of free lime (CaO or $Ca(OH)_2$) that reacts pozzolanically with the fine particles [12].

The savanna belt across west and central Africa leads in the production of the African locust bean (Parkia biglobosa), commonly known in Hausa as 'dawadawa', which is traditionally used in a fermented state [13]. The fermentation process involves the bean seeds being sorted and soaked in hot water for seven days or boiled for eight hours to de-hull and the water poured away as waste. This waste water has been found to contain chemicals such as calcium, iron, potassium, sodium and magnesium [14] which are equally present in cement, lime and bitumen. Such binders and certain locally specific plant-based materials such as gum arabic, other specific resins and the sap, latexes and juices from specific trees and are a [6] aimed to improving water proofing or wear resistance properties of vulnerable earth based construction. These materials can make a particular contribution in conserving energy in the manufacture of cementitious materials and of lightweight aggregates. A study on the reuse of paper de-inking sludge, undertaken in Spain, showed that, it has the potential as raw material for producing a binding material with pozzolanic properties [6]. Research findings showed that calcination paper sludge has higher pozzolanic characteristics as compared to other industrial pozzolanic by-products, such as fly ashes normally used in cements [9].

Therefore the purpose of this study is to evaluate the strength characteristics of soil bricks stabilised with African locust bean waste water. To realize this objective, soil stabilisation techniques already in use were studied and references made to other relevant studies.

II. MATERIALS AND TESTING METHODS

Materials

Soil

The soil material used for the study was taken from a depth of 300mm below ground level after removing the top soil from a local construction site closed to Wa Polytechnic in the Upper west region of Ghana. This Local construction site is where the indigenes fetch soil for construction of mud houses; hence the research deemed it fit to use samples from this site for soil test and brick moulding

African Locust Bean Waste Water (ALBWW)

African locust bean waste water was used in the study as the stabiliser. It is an agro-based waste water obtained from the processing of the African locust bean into local food condiments popularly called 'dawadawa' in the Hausa language. It was sourced from a local 'dawadawa' processing set-up in Kpaguri in the Wa Municipality in the Upper west region of Ghana.

Testing Methods and Procedures

Classification of Soil

Laboratory quality identification tests were performed on the soil used for the study. To ensure that stones and other foreign matter were removed, the soil was firstly passed through a 5mm network of sieves before it was characterized to assess its index properties. Sieve analysis was performed in accordance with Clause 7.4.5 of BS 1377 – 1: 1990 [15] to determine the grade of soil used through the proportion by mass of various sizes of particles present in the sample. This was followed by sedimentation test, using the jar method, to assess the silt, clay and sand/gravel fractions for the determination of the soil type.

The Casagrande Apparatus method was used in Atterberg Limits test and was conducted in accordance with Clause 7.4.3 of BS 1377 – 1: 1990 [15] to determine the plasticity range of the soil sample. To assess the amount of organic compounds present in the soil that may have an effect on the strength characteristics, the organic matter content test by ignition was performed. For the assessment of the soil's linear shrinkage, Clause 6.5 of BS 1377 – 2: 1990 [15] procedures were followed whiles the specific gravity was determined in accordance with BS 1377: 1990 [15]. Soil compaction test was conducted to determine the optimum water content for moulding of the soil bricks. This was done in accordance with BS 1377 – 1: 1990 [15].

Soil Bricks Production using African Locust Bean Waste Water

A BREPAK earth block press (see Fig. 1) that could deliver pressures of up to 35 MPa for brick production was available at the Wa Polytechnic Civil Engineering laboratory. The soil and water with or without locust bean waste water were thoroughly mixed manually. With four different batches (0%, 25%, 50%, 100 %,), fifteen (15) soil bricks with dimensions 200mm × 150mm × 100mm were produced from each batch (five bricks for compression test, five for abrasion resistance test and five for water absorption test).

Figure 1 BREPAK brick mould

The soil bricks were initially covered with damp plastic sheets and sacks for the first 7 days, according to the shrinkage test results. This was to prevent surface shrinkage cracking due to rapid evaporation which tends to promote undesirable loss and uneven distribution of moisture in the bricks. The plastic sheets were then removed after which the soil bricks were air dried at room temperature of 25°C for the remaining twenty-one (21) curing days.

Testing Methods and Procedures

Experimental tests such as dry density, compressive strength, water absorption and abrasion resistance were conducted on the bricks specimens. Three soil bricks which had no surface cracks visible to the naked eye were selected from each batch for these tests. The bricks were wiped of any dust or loose dirt stuck to them before being tested and the means and standard deviations reported.

Compressive Strength

The compressive strength test was performed in accordance with BS 3921: 1990 [15]. The test was done at the Wa Polytechnic, Civil Engineering Departments laboratory using the compression test machine.

Water Absorption by Capillary

The water absorption by capillary test was conducted according to BS 3921 [15]. The water absorption was measured by the increase in weight for bricks immersed in 5mm depth of water for ten minutes and subsequently the absorption coefficients (C_b) using the equation;

$$C_b = \frac{100 \times (M_1 - M_2)}{S\sqrt{t}} = g/cm^2/min.$$

Source: Centre for Development of Enterprise Guides [16]

Where, $M_1 - M_2$ is the mass of absorbed water in grams, S is the submerged surface area in centimetre square, and t duration of immersion in minutes.

Abrasion Resistance

For the abrasion strength test, BS 3921: 1921 [15] procedures were followed. The test was used to determine the surface hardness of the soil bricks and thus their resistance to wear. The abrasion coefficient (C_u) given by CDEG [16] expresses the ratio of the brushed surface, S (in cm^2) to the mass of the material detach by brushing ($M_1 - M_2$). The bricks were subjected to mechanical erosion applied by brushing with a metal brush in turns at forward and backward motions per about a second for 60 cycles. The mass of the detached (loose) matter was collected and weighed from which the abrasion coefficients (C_u) were calculated

$$C_u = \frac{S}{M_1 - M_2} = cm^2/g$$

III. RESULT AND DISCUSSION

Soil Characteristics

Various laboratory and field tests were conducted on the soil sample used in accordance with BS 1377-1990 [15] so as to determine it characteristics. The tests conducted were sieve analysis, sedimentation test, Atterberg limits, organic matter test, linear shrinkage test and specific gravity test. Table 1 presents the summary of characteristics of the soil used.

Sieve analysis

The results indicated that the soil is well graded with small amount of fine particles. The soil's coefficient of uniformity (C_u) and coefficient of gradation (C_g) were 6.4 and 1.2 respectively. Previous studies found that soil having C_u greater than 6 and C_g between 1 and 3 has its grain size distribution being at the optimum [17]. Thus, in terms of particle size grading, the soil used was well graded (Table 1).

Table 1: Characteristics of the Soil used

S/N	Soil Properties	Results
1	Sieve analysis	$C_u = 6.4$ and $C_g = 1.2$
2	Soil grade	Well graded
3	Silt fraction (%)	9
4	Clay fraction (%)	22
5	Sand/gravel fraction (%)	69
6	Soil type	Sandy clay loam
7	Liquid limit (%)	26
8	Plastic limit (%)	15
9	Plasticity index (%)	11
10	Plasticity range	Low plastic clay
11	Organic matter content (%)	1.7
12	Linear shrinkage (%)	3.8
13	Specific gravity	2.8

Sedimentation test

From the sedimentation test results, the soil was found to have a silt content of 9%, clay content of 22% and sand/gravel content of 69% (Table 1).This satisfies the recommendations made by previous studies that, for soil material to be suitable for brick production, the optimum fine content should be about 25% of which more than 10% should be clay [17].

Organic content

The amount of organic compounds present in the soil tested by ignition was 1.7% (Table 1). Past studies have shown that up to 2% organic compound in the soil does not have any significant influence on strength and durability [18].

Linear shrinkage

The linear shrinkage test was to establish the extent to which the soil can shrink and to help the curing regime. The soil recorded a maximum of 3.8% linear shrinkage after 5 days (Table 1). Previous studies showed that soil mixture with a maximum shrinkage of 6% is satisfactory for building purposes [16].

Specific gravity

The specific gravity of the soil tested was 2.8 (Table 1). It has been established that soils with specific gravities between 2.5 and 3.2 are suitable for building purposes [3]. In general, the soil sample used for the experimental studies was suitable for building purposes.

Atterberg limit

The result from the Atterberg limit test indicates that the soil has a liquid limit of 26%, plastic limit of 15% and plasticity index of 11% (Table 1). According to the Commonwealth Experimental Building Station [19] the preferred plasticity index for a soil for bricks, the mixture of gravel, sandy clays and clay loams should be between 10% and 20%. Thus the soil used could be classified as intermediate sandy clay loam as indicated in Figure 2.

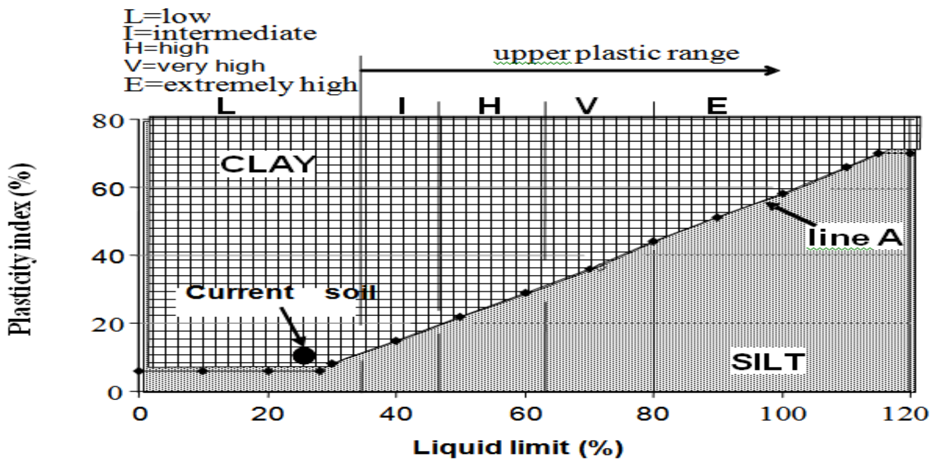

Figure 2: Plasticity Chart for Soil Classification

Soil Bricks Properties

Density

The mean densities of the bricks presented in Table 2, range from 2120kg/m^3 for soil bricks without ALBW content to 2167kg/m^3 for soil bricks with hundred percent ALBW content stabilisation. Previous studies had found that juicy liquid stabilisers enhance compressed soil density more than ash and pulverized stabilisers, hence the results was expected [21]. These values obtained fall within the ranges of 1200kg/m^3 and 2400kg/m^3 recommended by [20] as being suitable for masonry units.

Compressive Strength

From the results presented in Table 2, it is noticed that compressive strength steadily increased as the African locust bean waste water content increases. A compressive strength of 2.38N/mm^2, 3.29N/mm^2, 3.53N/mm^2, and 3.95N/mm^2, were obtained for the specimens A_o, $B_{25,}$ $B_{50,}$ and B_{100} respectively. The compressive strength of stabilised specimens' increased by 66% over the un-stabilised specimens when the soil was fully mixed with African locust bean waste water for bricks production.

This steady increased in compressive strength was expected as previous studies have found that soils stabilised with juicy liquid stabilisers improve the compressive strength more than with ash, pulverized and greasy stabilisers [18] and [21]. It has been found that the compressive strength of soil materials adequate for walls in low-rise and low-cost buildings is between 2N/mm^{2}and 4N/mm^2 [6]. Hence, these bricks compressive strength is within the recommended range and therefore is adequate in terms of strength for low rise buildings.

The compressive strength values and the African locust bean waste water percentage additions were highly correlated with a correlation coefficient, R^2 = 0.851 and this implies that the compressive strength of the soil bricks was highly influenced by the juicy liquid of the ALBWW by 85%. Again, from the regression equation, Y = 0.014 (X) + 2.12 0; where Y = compressive strength (dependent variable) and X = ALBWW content, (independent variable) it is clear that the compressive strength of the soil bricks has positive but weak relationship with the ALBW content. A percentage increase in the ALBWW content would increase the compressive strength of the soil bricks by 1. 4 N/mm^2

Table 2: Dry Density and Compressive Strength of Soil Bricks

ALBWW Content (%)	**n**	Dry Density (kg)		Compressive Strength (N/mm^2)	
		Mean	**Std. Deviation**	**Mean**	**Std. Deviation**
A_O	5	2120	9.165	2.38	0.234
B_{25}	5	2135	6.083	3.29	0.195
B_{50}	5	2161	11.080	3.53	0.081
B_{100}	5	2167	14.502	3.95	0.262

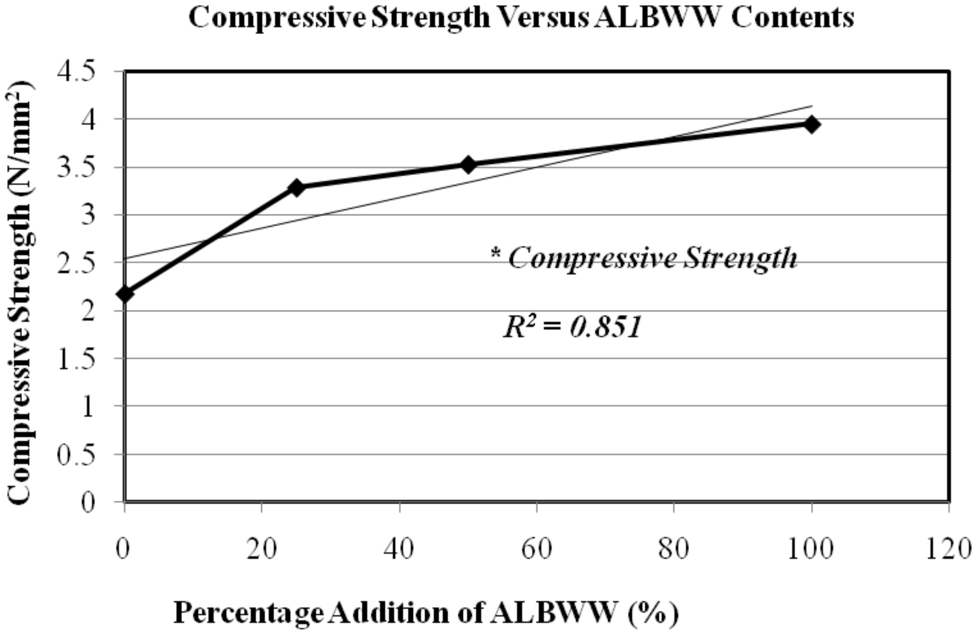

Figure 3: Relationship Between Compressive Strength and

Water Absorption by Capillary

The results given in Table 3, indicates that increasing levels of ALBWW has a steady declining effect on the amount of water absorbed by the bricks, that is, the higher the ALBWW content the less the absorption. The R-square value (0.643) shows that the low ingression of water into the soil bricks is about 64% influenced by the addition of the ALBWW content. From the regression equation obtained, Y = -0.086 (X) + 10.22, it is observed that a fairly negative relationship exists between the ALBW percentage additions and the water absorption coefficients. Hence, a percentage increase in ALBWW content would reduce the water permeating into the soil bricks by 8.6%.

The results confirms previous works that reported that soil with optimum clay content stabilised with agro-based juicy liquids has an increasing effect on density and compressive strength and decreasing effect on water absorption [22], [23] and [21].

Table 3: Water Absorption Coefficients of Soil Bricks

ALBWW Content (%)	Sample 1 (g/cm^2min)	Sample 2 (g/cm^2min)	Sample 3 (g/cm^2min)	Mean (g/cm^2min)	Std Dev.
A_O	7.906	15.969	15.811	13.229	4.610
B_{25}	6.541	5.060	3.004	4.902	1.824
B_{50}	6.166	4.427	3.320	4.638	1.435
B_{100}	3.472	2.842	2.688	3.004	0.418

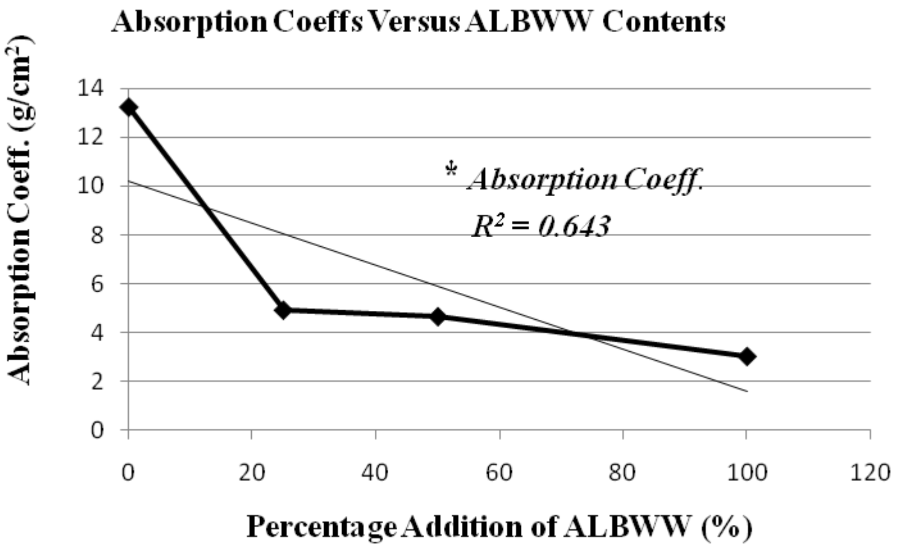

Fig. 4.0: Relationship Between Absorption Coeffs and ALBWW

Abrasion Resistance

The abrasion coefficient for bricks without ALBWW content was $6.45cm^2/g$. This increased steadily to $9.45cm^2/g$ for bricks stabilised with 100% ALBWW (Table 4). A high abrasion coefficient shows that a large brushing area is required to yield a certain amount of discarded material. This then implies that the increase in the ALBWW contents increased the bricks resistance to wear and tear by cutting and erosive agents such as wind, rain, snow, etc. These findings are similar to those of [24] and [21] who observed that agro-based juicy liquid wastes stabilizers increase compacted/compressed soil weight thereby improving its abrasion resistance.

Table 4: Weights and Abrasion Resistance Coefficients of Soil Bricks

ALBWW Contents (%)	Weight Before Brushing		Abrasion Coefficients	
	Mean (g)	Std Dev.	Mean (cm^2/g)	Std Dev.
A_O	2108	0.009	6.45	1. 229
B_{25}	2123	0.006	7.44	1.688
B_{50}	2148	0.010	8.84	1.817
B_{100}	2154	0.014	9.45	1.797

IV. CONCLUSION AND RECOMMENDATION

The results of the study support the conclusion that, the addition of the African locust bean waste water in the soil bricks has steadily improved its strength and durability. Even though the maximum values were achieved at the 100% ALBWW content, the results obtained at the 25% and 50 % ALBWW content met the required recommendations for earth housing. The ALBWW which is environmentally nuisance can be used to replace portable water and also as a stabiliser for masonry units in construction

The study recommended that, to produce cheap and environmentally-friendly stabilised soil specifically for rammed, cob, and wattle and daub walling, the soil type and its suitability must be established before using ALWW as mixing water.

LIMITATION

Hand mixed was used for mixing of the bricks ingredients. It would have been better if concrete mixer was used for the mixing to reduce possible evaporation of both mixing water and the juice stabiliser.

Soil sample was taken from one site near the Wa Polytechnic, it would have been appropriate if samples were taken from different site within the Wa Municipality to ascertain the suitability of the soil in the municipality.

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