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Physical and Geotechnical Properties of Fly Ash Blended Gaborone Dam Clayey Soil for Brick Production

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***Abstract*—This paper presents the properties of Gaborone Dam clayey soil blended with fly ash for the production of building stock bricks. The physical and engineering properties of the soil samples incorporating varying percentages 10, 20, 30 and 40% by weight of fly ash from Kalahari brewery clay was investigated. Particle size distribution, specific gravity, Atterberg limits and compaction tests were carried out on fly ash-blended soil samples. The results showed that the addition of fly ash did not affect the classification of the soil for both the Unified Soil Classification Systems and the AASHTO of inorganic lean sandy clay and group A-2-6, respectively. The maximum dry density decreased with increased ash content whereas the optimum moisture content increased with increased ash content. It can be concluded that bricks moulded with 10% fly ash blended clayey soil would be appropriate for strong and durable building purposes.**

Keywords—Atterberg limits, fly ash, shear strength, clayey soil, geotechnical properties, physical properties, clay bricks

I. INTRODUCTION

Clay is a natural material with high permeability and plasticity and in moulded form possesses the ability to regulate the internal relative humidity level to the most comfortable levels for humans [1]. Clay bricks are used for the construction of low-cost and modern buildings. Clay bricks provide a well-insulated and airtight house which means only less heating is necessary [2]. Due to the increasing concern for the environment especially with regards to waste management, many construction materials have been modified by incorporating pulverized wastes, either from renewable, natural, agricultural, industrial or mineral resources [3-7]. These agents are used mainly to modify properties such as porosity, water absorption, density, mechanical resistance and even thermal insulation for overall durability of the finished products [8].

Finished clay bricks are often in two basic categories - unfired and fired bricks. Even though extensive studies have been reported on the properties of bricks produced from clay blended with different admixtures, there is still much to contribute to knowledge on the strength and durability of such finished stock bricks. Bricks are one of the most durable man-made structural building materials so far. Numerous ancient brick buildings still standing for centuries are typical evidence of the durability of clay bricks. Production of bricks using clays is an ancient process, from several thousand years ago which has been practiced all around the world. Quality burnt clay bricks give attractive appearance in colour and texture, and do not require rendering, plastering, or other surface treatments [8-10].

Inclusion of waste (such as wastes from renewable or fossil and mineral resources) into building materials could be an interesting way to minimize pollution associated with soil contamination (landfill) or by removing toxic materials. Production of fired bricks from waste materials uses waste material(s) to substitute a portion and follows the traditional way to kiln fire the material(s) to produce bricks. Many researchers have studied the production of fired bricks from waste materials. Chen *et al.* [11] studied the feasibility of utilizing hematite tailings and class F fly ash together with clay to produce bricks. El-Mahllawy & Kamdeel [12] used different proportions fly ash to stabilize the Egyptian montmorillonite clay and found that fired brick clay bricks are used in everyday life, but is disadvantaged by the cost of energy and emission of greenhouse gases - carbon dioxide, fluorine and sulphur. The chemical and structural modification of clay material during firing generally improves the mechanical strength and durability of bricks. Knappett & Craig [1] found out that the binding materials should be crushed and passed through 75 µm sieve in order to speed up the rate of chemical reaction with water and soil.

The production of clay bricks at the Gaborone Dam site is currently guided solely by the rule of thumb. The workers lack the scientific knowledge of the physical and geotechnical properties of both the soil materials and the fly ash (admixture) utilized as binders. Consequently, indiscriminate mining of soil and litters of unwanted brick waste from substandard materials and poorly moulded or unsatisfactorily fired products result in soil pollution and environmental degradation of the sites. These make the site a breeding site for mosquitoes, pests and other environmental issues.

Production of strong and durable of burnt bricks may become a vital tool required to solve the problem of housing deficit and youth unemployment in Botswana particularly in areas with relatively high deposit of clay. This study was conceived to help the brick moulders identify suitable soil materials and the appropriate admixture content required for strong and durable brick products. This paper therefore presents the geotechnical properties of Gaborone dam clay mixed with different quantities of ash content.

II. DESCRIPTION OF THE STUDY AREA

Gaborone Dam is located south of Gaborone at the central geographical co-ordinate of 24° 43′ 5.87″ S, 25° 54′ 26.92″ E [13]. The dam is the biggest in Botswana with a capacity of 141,400,000 cubic meters. Gaborone has a hot semi-arid climate with very hot sunny summer days and cool nights. Gaborone Dam was first built in 1963 to supply water to the urban centre of Gaborone when demand for water exceeded the supply from the older Notwane Dam. The dam was used to provide water for the domestic and industrial needs of Gaborone and Lobatse. However, the effects of climate change coupled with sparse and unpredictable precipitation have drastically reduced the volume of the reservoir in recent years. Soils around the dam areas generally consist of sandy loams, clays and sandy clay loam types. Good fertile soils are found in depressions and flood plains [14]. The area around the dam is underlain with the Gaborone granite and the dominant soil types are sandy loam and clays soils which are conducive for vegetation. Fly ash admixture commonly used for the brick-moulding purposes are sourced from the Kalahari Brewery Limited, Gaborone, Botswana.

III. MATERIALS AND METHODS

A. Materials

Soil samples were collected from Gaborone dam site located approximately 11 km south of Gaborone city centre. Soil sampling, preparation and testing were carried out in line with BS 1377 [16]. Geotechnical tests such as the grain size distribution, hydrometer analysis, Atterberg limit tests and specific gravity were performed on the soil samples for classification purposes. Fly ash was sourced from the Gaborone Plant of Kalahari Brewery Limited.

B. Particle Size Distribution

Particle size analysis was used to determine the size range and grading of soil particles. This was required to determine the engineering properties and properly classify the soil. Particle size distribution and soil classification were based on the AASHTO and the Unified Soil Classification System (USCS).

C. Particle Density Determination

Particle density determination is essential for computing the particle size analysis from a sedimentation procedure (hydrometer analysis). It is also significant when compaction and consolidation properties are considered. Pycnometer method was used to find the particle density in reference to BS 1377-2 [16].

D. Atterberg Limits

The soil sample was blended with varying coal ash contents (0%, 10%, 20%, 30% and 40%) by weight of soil. Each soil-coal mixture was passed though sieve size 0.075 mm and the consistency limit namely, the liquid limit (LL), plastic limit (PL) and the plasticity index (PI) were determined in line with BS 1377 [16]. These tests were the basic measure of the critical water content of a fine grained soil. Liquid limit (LL) is the minimum water content (expressed as a percentage of the weight of the oven-dried soil) at which a part of soil cut by a groove of standard dimension will flow together for a distance of 12 mm at the boundary between the liquid and plastic states of consistency. The LL was determined by a cone penetrometer apparatus. The plasticity of the soil is the ability of the soil to undergo deformation without cracking. The plastic limit (PL) is the moisture content where the thread breaks apart at a diameter of 3 mm. It is the moisture content (expressed as a percentage of the weight of the oven-dry soil) at the boundary between the plastic and semisolid states of consistency.

E. Compaction test

Compaction test based on Proctor method was used to determine the optimal moisture content at which the soil would achieve its maximum density. Maximum density depends on the type of material and the input energy during compaction. Compaction test was carried out in accordance with BS 1377- 4 [17].

IV. RESULTS AND DISCUSSION

A. Physical Properties of Soil and Fly Ash

The physical properties, the Atterberg limits and the compaction test results of the Gaborone Dam soil samples as conducted in the Geotechnical laboratory are summarized in Table 1. The specific gravity of the soil and fly ash were 2.76 and 2.50 respectively. The Brunauer-Emmett-Teller (BET) specific surface area of the soil sample passing through 75 µm sieve was 35.72 m^2/g. The specific gravity obtained for Gaborone soil was slightly lower than the findings of Kazmi et al. [2] and comparable with the results of Ukwatta et al. [17].

B. Particle Size Distribution

Particle size analysis was used to determine the size range and grading of soil particles in order to classify the soil appropriately and to determine which of the different size ranges was likely to control the engineering properties of the soil. The particle size distribution curves of the soil and coal ash are shown in Fig. 1. The average coefficients of uniformity and curvature were 10 and 1.6 respectively.

TABLE 1: PHYSICAL PROPERTIES OF SOIL SAMPLES

Soil gradation	
Gravel fraction (%)	0
Sand fraction (%)	28
Silt and clay (%)	72
Specific gravity (G_s)	
Soil	2.76
Fly ash	2,50
Atterberg limits	
Liquid limit (LL) %	28
Plastic limit (LL) %	17
Plasticity index(PI) %	11
Colour	Reddish-brown
Effective grain sizes	
D_{10} (mm)	0.03
D_{30} (mm)	0.12
D_{60} (mm)	0.3
Coefficient of uniformity, C_u	10
Coefficient of curvature, C_c	1.6
Compaction test	
Maximum dry density (kg/m^3)	1868
Optimum moisture content (%)	15

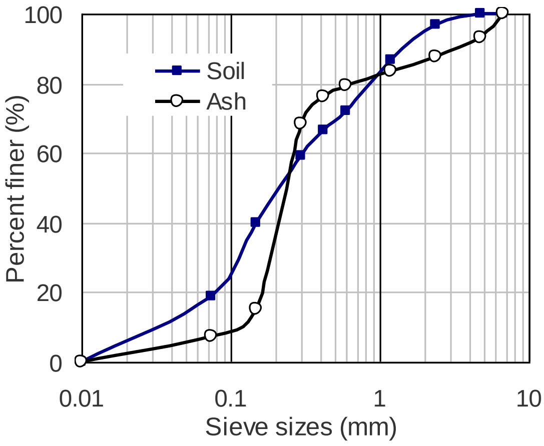

Figure 1. Particle size distribution curve for soil and coal ash

About three quarters of the soil mass was finer than 75 µm, which accounted for the clay and silt content of the soil. The soil was predominantly silty clay with some quantity of sand, that is, lean clay with sand. The particle size distribution of soil passing through 75 µm sieve blended with 0%, 10%, 20%, 30% and 40% fly ash passing through 75 µm sieve were determined by hydrometer analysis. The results are plotted in Fig. 2. The soil sample was well-graded and the average particle size was about 5 µm. The analysis of soil samples without fly ash is shown in Fig. 2a, while varying quantities of fly ash contents by percentage weight of soil sample is shown in Fig. 2b.

It is evident from the hydrometer analysis that the percentage finer increased with increase in the quantity of ash content. The different particle sizes settled at different times. The higher the percentage of fine particles the higher the rate of settlement of particle as the ash content increased from K' values of 5.81 to 5.83. These results agree with the soil materials from Northwest Sardinia Alghero district used for traditional brick production [18].

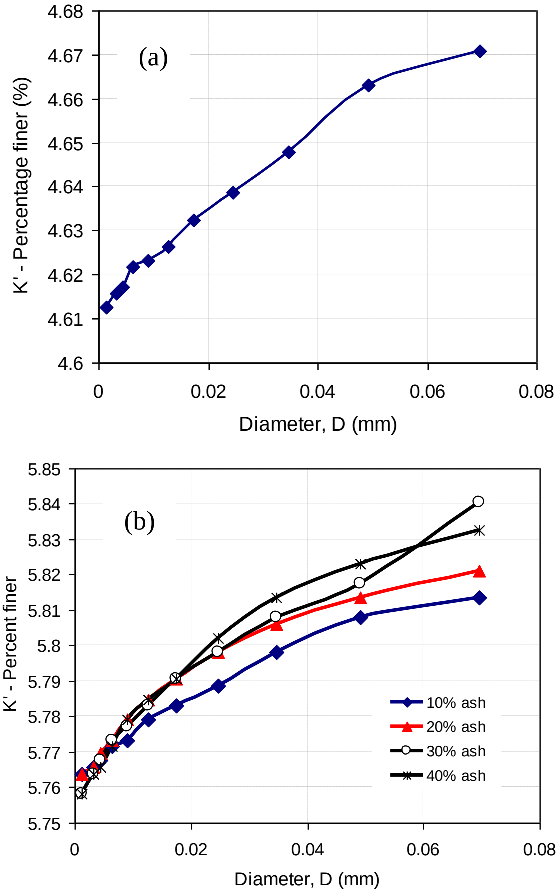

Fig. 2. Particle size distribution of (a) soil and (b) soil with varying fly ash contents

C. *Specific Gravity*

The specific gravity test was performed using pycnometer. The soil is denser that fly ash of specific gravity of 2.76 and 2.50 respectively. The trend of specific gravity for different ash contents is plotted in Fig. 3. The specific gravity of the soil materials decreased perfectly linearly with increasing ash content in the form of $G_x = -0.0026x + 2.76$, where x is the percentage fly ash content.

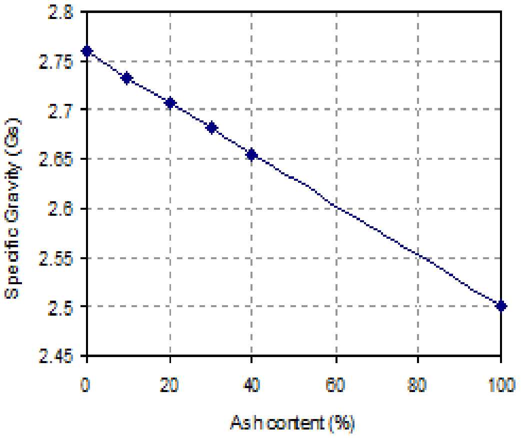

Fig. 3. Trend of specific gravity of soil with varying ash contents

D. Atterberg Limits

The consistency limits of the soil were 28%, 17% and 11% for the liquid limit (LL), the plastic limit (PL) and the plasticity index (PI), respectively. Since the PI was within the range 3 – 15%, it can be inferred that the soil is slightly plastic clay. This soil was found to have plastic limit roughly below 20 and liquid limit in the range of 25 and 40. Hence, according to the AASHTO classification of soils, the predominant constituent materials are silty and clayey sands. The soil falls within the group A-2-6. According to the Unified Soil Classification System (USCS), the soils can be classified as CL-Inorganic clays of low plasticity, that is, LL<50, PL >7 and plots above A-line of Das' plasticity chart.

The Atterberg limits were also determined for the soil with varying contents of coal ash of 0, 10, 20, 30 and 40%. The LL, PL and the PI are shown in Fig.4.

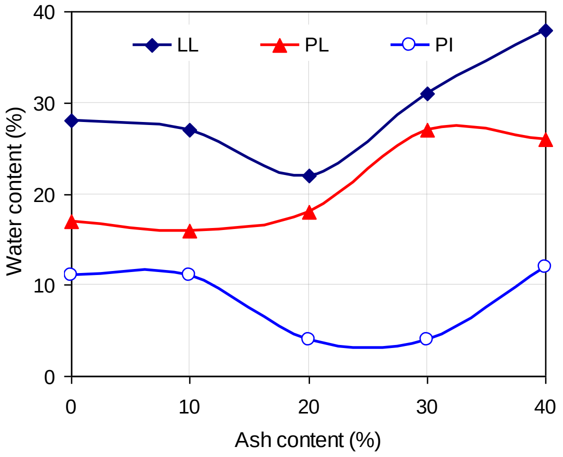

Fig. 4. Consistency limits of soil with varying ash contents

The LL and PL of the soil samples increased as fly ash content increased. However, at 30% ash content there is a kink decrease in plasticity index simply because there was a huge increase in plasticity index from 20% ash content. The increment in liquid and plastic limits as ash content increased was probably because of the increase in the amount of the clay-sized particles in the mixture since fly ash was well graded with a large amount of clay sized particles.

E. Compaction Test

The plots of the dry densities against moisture content shifts to the right and the slope of the concave decreased as the ash content increased (as shown in Fig. 5), indicating a drop in the maximum dry density. An increase in the moisture content was probable due to the mass of fines increases more water will be needed to be absorbed. The maximum dry density is inversely proportional to the optimum moisture content as shown in Fig. 5.

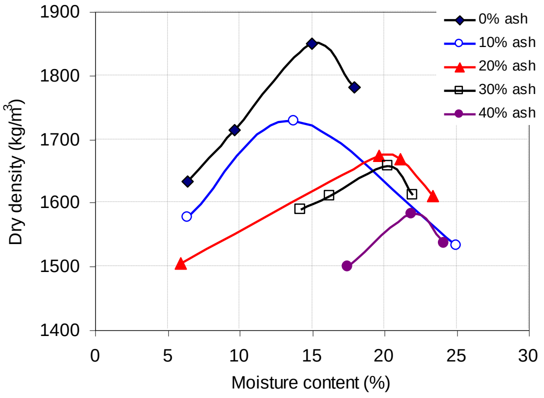

Fig. 5. Compaction test results showing the curves of dry density vs moisture content, for varying fly ash contents

In Fig. 6a, the maximum dry density plotted against the ash content deviated as the ash content increased. The maximum dry density at 0% and 40% ash contents were 1868 kg/m^3 and 1580 kg/m^3 respectively. This is probable due to the increase in the volume occupied by fines which decreased the weight of the mixture since the ash was less dense that the soil. However, the plot of the optimum moisture content against fly ash content as shown in Fig. 6b shows that there is a linear increment in the optimum moisture content with respect to the ash content. This implies that more water is needed to compact fly ash blended soil mass. The maximum dry density is inversely proportional to the optimum moisture content. This also translates to higher the compacting effort. As the fly ash content increased up to 10%, the maximum dry density and the optimum moisture content decreased almost linearly, however, the former declined more sharply. Conversely, beyond 10% fly ash content, the maximum dry density decreased at decreasing rates, while the optimum moisture content increased at decreasing rates.

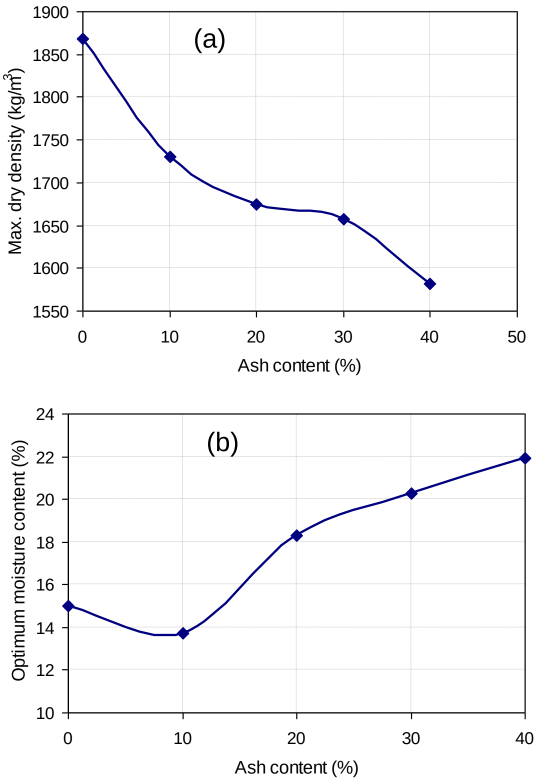

Fig. 6. Compaction test results showing the curves of (a) maximum dry density, and (b) optimum moisture contents for varying ash contents

V. CONCLUSIONS

The article presents the properties of Gaborone Dam soil to evaluate its suitability with or without the fly ash admixture for the production of stock bricks for building purposes. The following conclusions were drawn from the study.

1. Gaborone Dam soil is predominantly silt and clay (72% finer than 75 μm) with 28% sand.
2. The class of the soil is CL-inorganic clays of low plasticty. It soil is lean clay with sand based on the Unified Soil Classification System (USCS). The soil belongs to group A-2-6 based on the AASHTO classification system.
3. The maximum dry density (MDD) and the corresponding optimum water content (OMC) of the soil were 1868 kg/m^3 and 15%, respectively, while 40% fly ash blended soil had MDD and OMC of 1582 kg/m^3 and 21.9%, respectively.
4. Regardless of the ash content up to 40%, the classification of fly ash blended soil remained CL-Inorganic clays of low plasticity or simply lean inorganic clay with sand.
5. With respect to the compaction properties, 10% fly ash content gave the best geotechnical properties without structural compromise.
6. The specific gravity of ash blended soil decreased with ash content because the soil is denser than the fly ash. However, 10% fly ash content remained the most ideal for clay bricks with minimal effect on the bulk density of clay bricks.

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