ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 9, Issue, 02, pp.46401-46406, February, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

EFFECT OF COFFEE HUSK ASH ON GEOTECHNICAL PROPERTIES OF EXPANSIVE SOIL

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ARTICLE INFO

Article History:
Received 15th November, 2016
Received in revised form
09th December, 2016
Accepted 18th January, 2017
Published online 28th February, 2017

Key words:
Road Construction,
Expansive Soil,
Coffee Husk Ash,
Stabilization.

ABSTRACT

Road constructed on an expansive soil needs special attention during the design and construction stages. This study investigates the possibility of using coffee husk ash as an expansive soil stabilizer. Coffee husk is a by-product of coffee beans: when coffee husk is burnt the resulting ash is coffee husk ash (CHA). To investigate the effect of adding CHA to an expansive soil, laboratory experiments such as Proctor density, swelling index, consistency limits and unconfined compressive strength (UCS) tests were performed for different percentages of CHA. Standard Procter tests were conducted to evaluate the compaction behavior and unconfined compressive tests were performed on samples of 5 cm diameter and 10 cm height, after curing for 1, 7 and 14 days. The laboratory test results show that the addition of CHA increases compressive strength and decreases swelling ratio and shrinkage. From Atterberg limit and Proctor tests a decrease in the plasticity index and optimum moisture content while an increase in dry density as the CHA percentage increases were observed. The study reveals that the addition of CHA improves the geotechnical properties of expansive soil.

Citation: Atahu, M. K., Saathoff, F. and. Gebissa, A. 2017. "Effect of coffee husk ash on geotechnical properties of expansive soil", *International Journal of Current Research*, 09, (02), 46401-46406.

INTRODUCTION

Soils that have characteristics of swelling during wet and shrinking during dry seasons are classified as an expansive soil. The shrink–swell properties of these soils detrimentally influence the construction project design, performance and lifetime, especially of lightweight civil engineering infrastructures [Gourley *et al*., 1993]. Major engineering problems are volume changes due to cyclic swelling and shrinking behavior of the soils during the wetting and drying seasons respectively. The cyclic swelling and shrinkage of the soils can lead to differential heave, settlement and creep, decrease in bearing capacity and shearing strength, and high erosion susceptibility and instability when exposed in natural slopes, road cuts, or open excavations [Gourley *et al*., 1993]. Expansive soil (mainly black cotton soil) is one of the major soil deposits in Ethiopia, covering about 40% of the area [Fekerte *et al*., 2009]. Black cotton soil (BC soil) is a highly clayey soil. The black color in BC soil is due to the presence of titanium oxide in small concentrations and it has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in color [Kavish *et al*., 2014].

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Most of the roads constructed in Ethiopia on the shrink–swell soils are susceptible to damage before expected design lifetime. Early cracking of road surfaces constructed on expansive soils is a common failure in the country. This happens a few years or sometimes even months after being opened for public use. The high plasticity, compressibility, and swelling and shrinking nature of the soil is usually improved by removing the problematic soil and replacing it with selected material or stabilizing it with lime and cement. Stabilization, in a broad sense, incorporates methods employed for modifying the properties of the soil to improve its engineering performances. Stabilization is used for a variety of engineering works; the most common application is in the construction of roads and air-field pavements [Kiran, 2013]. Factors that should be considered in choosing stabilization materials are abundance, cost, and effectiveness. Ethiopia produces a large volume of coffee beans every year, around 450,000 tons during 2013/2014 alone [http://ethioagp.org/ethiopian-coffee-exports-to-hit-record-in-2015]. Coffee husk is a by-product of coffee. The main objective of this study is to investigate the potential application of coffee husk ash as stabilization material specifically for road construction.

LITERATURE REVIEW

Over the years research communities have studied the characteristics of different kinds of expansive soils and examined the possibility of improving the properties of such soils.

Bell (1999) investigated damage due to the shrink–swell characteristics of soils on civil engineering infrastructures and estimated that it costs billions of dollars. Due to a large extent of damage and an increase in a construction project cost, engineers and researchers carried out many investigations to figure out the possibility of using an increasing amount of solid waste to improve the soil's properties [Ehammed, 2004]. Nyankson *et al*. (2013) explored the effect of lime contained in eggshell and its application in the stabilization of shrink–swell soils and the sample mixed with 8% eggshell powder showed a decrease in the plasticity index (PI) and free swell index (FSI) and a high silt/clay fraction. Mousa *et al*. (1998) reported the possibility of using olive waste, finding that the addition of 2.5% by weight of burned olive waste increases the unconfined compressive strength and the maximum dry density, while the addition of 7.5% olive ash by weight minimizes the swelling pressure of the soil. Haji Ali *et al*. (1992) found that the addition of rice husk ash (RHA) enhances not only the strength development but also the durability of lime-stabilized residual soil. Stabilized soil with the optimum RHA content suffers the least detrimental effects of saturation.

Therefore, it can be inferred that the use of RHA in the chemical treatment of residual soil for construction of roads, airfields, etc. would require reduced annual maintenance costs [Haji *et al*., 1992]. Soil stabilized with the addition of waste (bagasse ash) gave somewhat improved strength values but the blend with cement and lime gave more increased strength values [Kiran, 2013]. Satyanarayana *et al*. (2013) identified that the addition of fly ash to expansive soil increases the strength and decreases the swelling characteristics. Abd El-Halim *et al*. (2014) concluded that sawdust has the potential to improve the hydro-physical properties of expansive soils, especially when added to soil in between one to two percent on dry weight basis. Above this percentage the improvement was much less significant and warranted by the clay content decrease. In addition, fine sawdust can be used to minimize the development of desiccation cracks and the shrinking behavior of expansive soils. Moreover, the sawdust waste material can potentially reduce stabilization costs by utilizing waste in a cost-effective manner [Abd El Halim, 2014].

Properties of coffee by-products are less known and less research has been conducted on how to use these waste materials in an effective manner. Coffee husk contains some amount of caffeine and tannins, which makes it toxic in nature, resulting in disposal problems. However, it is rich in organic matter, which makes it an ideal substrate for microbial processes for the production of value-added products, such as fertilizers, livestock feed, compost, etc. However, these applications utilize only a fraction of available quantity and are not technically very efficient [Ashok Pandey, 2000]. Combustion of this type of waste material is a common practice in farms; the coffee husk ash reject is becoming a worrying factor for environmentalists. Coffee husk ash reject (CR) is constituted mainly of calcium and potassium, making it possible and interesting to investigate the possibility of using this material as a raw material in the ceramic formulation. It has been found to have a positive effect [Acchar, 2013]. No study has been reported on the usage of CHA for soil stabilization. Its use will however potentially improve the soil properties and reduce the environmental impact caused by this waste material. The aim of the present study is to analyze the effect of coffee husk ash on the plasticity, swelling, compaction, and strength behavior of expansive soil. A series of tests were carried out to study the effect of CHA on soil properties.

MATERIALS AND METHODS

Study Area and Sampling

The site selection and sampling were carried out in west Shoa zone of Oromia state, around Ambo town, Ethiopia (8 58'10.3''N 37 56'26''E ALT=2102m) as indicated in Figure 1. The mean annual temperature and rainfall of Ambo area is about 18.64ºC and 968.7 mm, respectively [Ogato, 2013]. Ambo and its surroundings are mainly covered by pellicvertisols (known for their extensive cracking to a depth of 50 cm or more with seasonal drying) with poor drainage [Balemi, 2012]. Representative soil samples were collected from different sites in Ambo in such a way that the sites should represent a wide spectrum of factors and were collected according to standard soil sampling procedures.

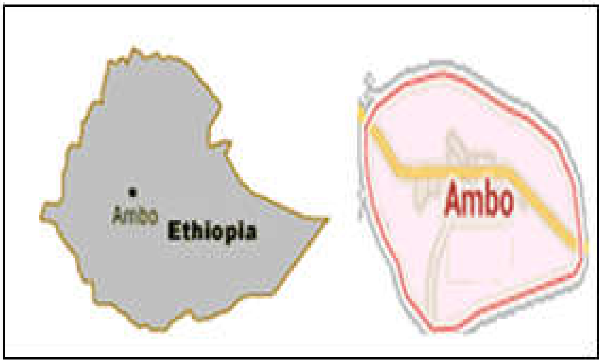

Fig.1. Location map of sampling area

Black Cotton Soil and its Geotechnical Properties

Black cotton (BC) soil is classified as an expansive soil due to its high swelling and shrinkage capacity as a result of changes in moisture condition. Due to its intensive shrink–swell characteristics, it forms a very poor foundation material for road construction, usually resulting in surface cracks and fractures causing an opening during dry seasons as shown in Figure 2. BC soil has very low strength; soaked laboratory California Bearing Ratio (CBR) values of BC soils are generally found in the range of 2 to 4%. Due to very low CBR values of BC soil, excessive pavement thickness is required for the design of flexible pavement [Kavish, 2014].

Fig. 2. Cracks on Ambo–Addis Ababa road

To characterize the sample, different laboratory tests such as particle size distribution, Atterberg limits, swelling index, specific gravity, permeability, organic content, compaction, and unconfined compressive strength tests were performed according to the guidelines of the American Society of Testing and Materials (ASTM) and the geotechnical properties of the tested soil are given in Table 1. Grain size distribution and grain shape influence the geotechnical properties of the soil. As shown in Figure 3 the grain size analysis of the soil sample shows that the fine content (silt and clay) is 85.2% on average. According to the Unified Soil Classification System (USCS) if more than half of the material is smaller than no. 200 sieve (75 µm sieve size) the soil is classified as fine-grained soil.

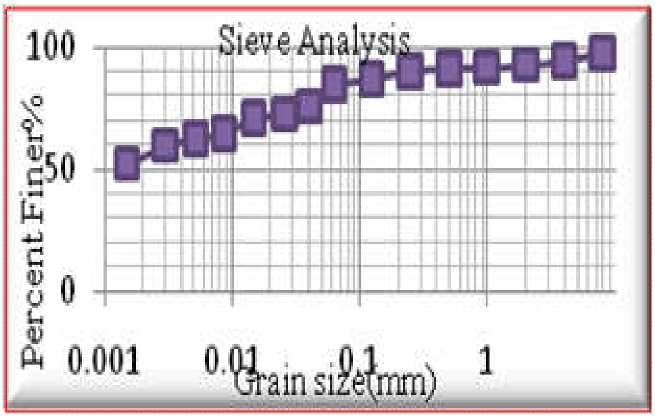

Fig.3. Grain size distribution of BC soil

Further classification was done after Atterberg limit test, using a plasticity chart and the results show that the soil is classified as A-7-5 or High Plasticity Clay (CH) according to American Association of State Highway and Transportation Officials (AASHTO) and USCS, respectively. From the test results the soil is classified as CH with low permeability and high swell–shrink capacity.

Table 1. Properties of soil used for this study

Test			Result
Grain size analysis	Course	Gravel%	4.7
		Sand%	10.1
	Fine	Silt%	30.33
		Clay%	54.87
Consistency limit	Liquid limit%		93.4
	Plastic limit%		40.46
	Plasticity index		52.94
	Shrinkage limit%		16.72
Swell characteristics	Free swell ratio		2.5
	Volumetric shrinkage%		142.9
Compaction characteristics	Optimum moisture content %		37.2
	Maximum dry density (gcm^{-3})		1.242
Strength parameters	UCS (KPa)		81.16
	Cohesion (KPa)		40.55
Soil property	Specific gravity		2.685
	Coefficient of permeability(ms^{-1})		$2.885x10^{-11}$
	Organic content (%)		7.82
	Activity of soil		0.96

Coffee Husk Ash

Coffee husk is a by-product of coffee. Ethiopia produces coffee abundantly; its husk requires a large area for storage and it is environmentally unfriendly. The main focus of this study is the utilization of waste (coffee husk) for road construction to improve the properties of expansive soil and to increase economic and environmental benefits. The coffee husk is collected from factories and farms and kept in a furnace at 550°C. The resulting ash is CHA, as shown in Figure 4.

Fig.4. Coffee husk ash

Table 2. Properties of CHA

Test		Result
Grain size analysis	Gravel%	0
	Sand%	57.1
	Fine%	42.9
Specific gravity(gcm^{-3})	2.03	
Free swell ratio	Non swelling	

Some properties of CHA are presented in Table 2 and the grain size analysis result is presented in Figure 5. The usage of CHA for the treatment of expansive soil is evaluated.

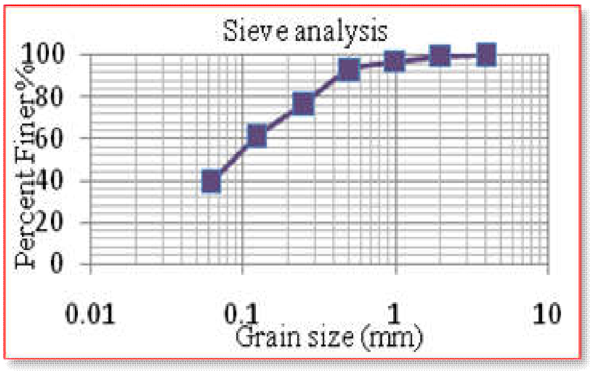

Fig. 5. Grain size analysis of CHA

Sample Preparation

The samples are collected according to the standard sampling procedure. The soil is prepared for different tests after air drying and then mixed with coffee husk ash on a dry weight basis. Proper care is taken to produce a homogenous mixture. For the unconfined compressive strength test, the specimens are prepared in the laboratory depending on the Proctor data at the required maximum dry density and optimum moisture content with different percentages of CHA and were kept at room temperature and cured for 1, 7 and 14 days.

RESULTS AND DISCUSSION

Consistency Limits

The effect of CHA on consistency behavior of the soil sample is determined by the evaluation of Atterberg limits.

ASTM D4318 Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils is performed to determine the plastic and liquid limits of a fine-grained soil. Figure 6 indicates that the addition of CHA in different percentages has a noticeable effect on the liquid limit and plasticity index of the soil. As the amount of CHA increases the plasticity index decreases and the soil classification goes from highly plastic clay (CH) to highly plastic silt (MH).

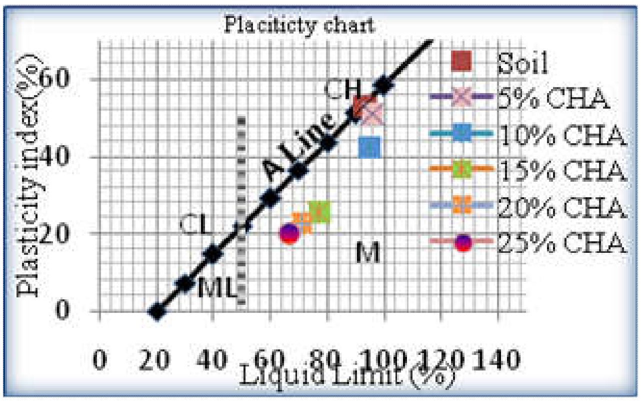

Fig.6. Plasticity chart showing classification of soil and soil/CHA mixture

Compaction

Compaction is the artificial improvement of the mechanical properties of the soil, which increases the resistance and reduces the deformation capacity and void ratio. To determine optimum moisture content and maximum dry density of the expansive soil and treated soil, standard Proctor compaction tests were performed according to ASTM D698, at different percentages of CHA. Figure 7 shows the behavior of the soil due to the addition of different percentages of CHA, up to 20%. As the percentage of CHA increases there is an increase in dry density and a decrease in moisture content.

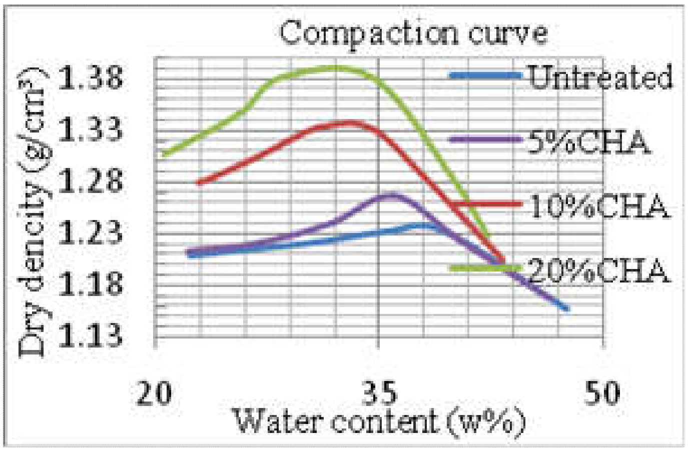

Fig.7. Moisture–density relationship of soil and soil/CHA mixtures

Free Swell Index and Volumetric Shrinkage

Soil swelling is an expansion in volume that causes significant problems leading to serious damage and economic consequences in construction sectors, mainly in road construction. The free swell index (FSI) test is performed on untreated and treated soil samples by slowly pouring 10 grams of dry soil and 10 grams of soil/CHA mixture passing through a 425 µm sieve in a 100 ml measuring jar filled with distilled water. The swollen volume of expansive soil and expansive soil/CHA mixes are recorded as final volume (Vf) after 24 hours and the initial volume is recorded as Vi. The FSI is determined using Equation 1 and the results are shown in Figure 8.

$$FSI\,(\%) = \frac{(Vf-Vi)}{Vi} * 100 \qquad \text{Eq.1.}$$

Volumetric shrinkage is the decrease in volume of a soil mass when the water content is reduced from a given percentage to the shrinkage limit and which is expressed as percentage of dry volume of the soil mass [Tariful *et al*., 1999].

The volumetric shrinkage of soil and soil/CHA mixtures is determined using Equation 2.

$$Vs(\%) = \frac{(Vw-Vd)}{Vd} * 100 \qquad \text{Eq.2.}$$

where Vs is volumetric shrinkage and Vw and Vd are wet and dry volume of the samples, respectively. Volumetric changes of the soils may cause unfavorable effects such as damage to buildings and cracks in roads. The effect of the addition of CHA on the volumetric shrinkage of soils is presented in Figure 8 and shown in Figure 9.

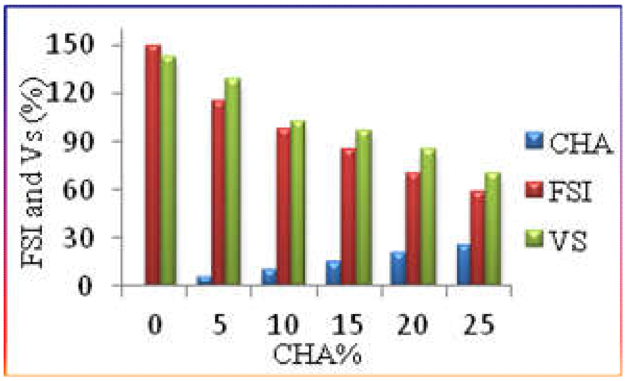

Fig.8. Effect of CHA on free swell index and volumetric shrinkage

The BC soil used for this study has a high swelling and shrinking capacity, and the addition of CHA on soil samples shows significant change on volumetric shrinkage. The FSI value decreases from 150% to 58% and the Vs value decreases from 143% to 70% by adding 25% CHA, which indicates about a three-fold and two-fold reduction respectively compared to untreated soil.

Fig.9. Shrinkage behavior with (1) expansive soil, (2) +10% CHA and (3) +25% CHA

Unconfined Compressive Strength

The unconfined compressive strength (UCS) test is a standard and the most common strength test used to characterize stabilized soils and has been found to be a competent indicator of the durability of soils [Agapitus Ahamefule Amadi, 2014]. The tests are conducted according to the ASTM D2166 method for unconfined compressive strength of cohesive soils. Specimens for the UCS test were prepared with 5 cm diameter and 10 cm height and cured at room temperature for 1, 7 and 14 days. The UCS results of soil and soil/CHA mixtures with different percentages of CHA and curing time are presented in Figure 10.

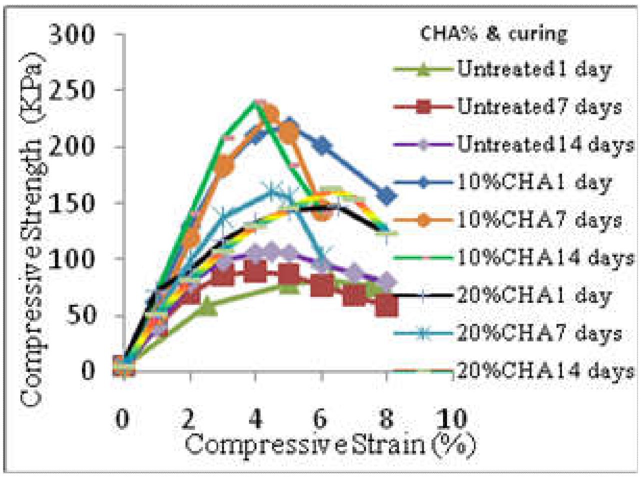

Fig.10. Unconfined compressive strength curves for different percentages of CHA

The addition of CHA to soil samples shows considerable improvement. As the percentage of CHA increases from 0 to 10% the UCS indicates significant increment and consequently yields a higher load. As shown in Figure 11 compressive strength values decrease with the addition of higher percentages of CHA and increases with curing time.

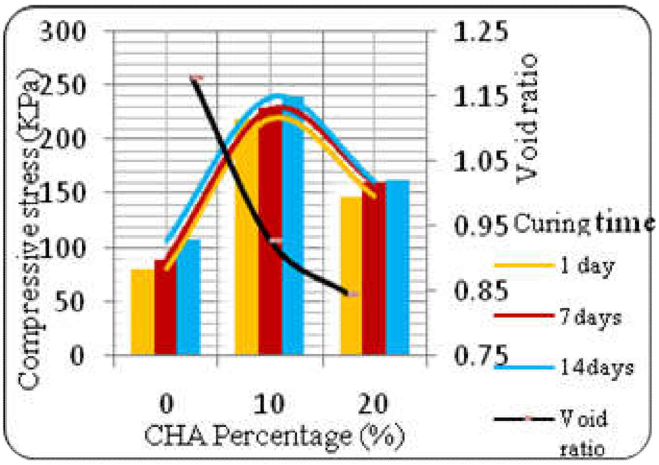

Fig.11. Effect of CHA and curing time on compressive stress

Conclusion

The study investigated the potential use of CHA for geotechnical property improvement of BC soil. Commonly used laboratory tests such as Atterberg limits, free swell index, standard Proctor tests, and unconfined compressive strength tests were performed to evaluate the behavior of expansive soil treated with coffee husk ash. The tested soil is clays of high plasticity, with high swell–shrink capacity and low permeability. The obtained result reveals that the addition of CHA reduces the plasticity of the soil and increases both the maximum dry density and the unconfined compressive strength. It is also found that the addition of higher percentages of CHA results in a decrease of both the unconfined compressive strength and maximum dry density of the soil. The swell and shrinkage tests indicated that the swelling and shrinking capacity of the soil stabilized with the addition of 25% CHA reduced by more than half compared to the untreated soil. The study indicates the potential usage of CHA in road construction, but further study on the effectivity, economy, optimum value of CHA and durability of CHA-stabilized soils is essential.

Acknowledgment

The financial support from Katholischer Akademischer Ausländer-Dienst (KAAD) is gratefully acknowledged.

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