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Coffee Husk Ash and Cement as Special Ingredients: Stability Analysis on Black Cotton Soil

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ABSTRACT *In the current study, the soil samples were collected from the Agri-bed zones of Ambo town and tested for its physical characteristics in the Civil Engineering laboratory, Awaro campus, IOT, Ambo University. The physical tests on the soil samples were proven that the type of soil in the study area is 'Purely Black Cotton Soil (BCS) having very poor shear strength, high swelling tendency and shrinkage nature and that are very hard when dry, but loses its strength completely in wet condition. These soils are clays of high plasticity index and very weak so that they cannot be used as the construction material. For improving the engineering properties of such an expansive soil and to make it more stable, soil stabilization using the suitable ingredients is of prime importance. It was done by the use of heavy compaction, proportioning and addition of different type of admixtures and stabilizers. Although there are several methods to stabilize the expansive soil, the locally available ingredients such as Coffee Husk Ash (CHS) and Cement were used in our study to check with the stabilization nature on BCS and their effect on the properties of BCS. For the stabilization technique, a required amount of Coffee Husks were collected from the grinding mill in Addis Ababa city, dried, powdered and burnt for making the husk ash. Keeping the cement percentage as the constant (2%), only the CHA were added to the original soil samples in different proportions such as 4%, 8% and 15%. Based on the observation from the number of trails using Coffee Husk Ash and Cement as the stabilizing agents, the swelling/shrinkage of the investigated soil sample have considerably reduced with the trail–3 in which 15% CHA was added with 2% cement and 83% original soil sample.*

KEY WORDS *Black Cotton Soil, Coffee Husk Ash, Expansive soil, Free Swell Index, Lime, Textural Class*

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I. INTRODUCTION

Soil is a natural aggregate of mineral grains which can be loose or moderately cohesive, inorganic or organic in nature that could be separated by means of simple mechanical processes [5-9]. A large portion of the earth is covered by soil, and it is widely used as construction and foundation material. In Ethiopia, wide range of the land is covered with expansive soil [1, 2, 4]. Expansive soil is a clay soil that is prone to large volume changes (swelling and shrinkage) that are directly related to changes in water content [10, 11]. In other word, it is that expands when water is added, and shrinks when it dries out. Expansive soils can be found in humid environments where expansive problems occur with soils of high plasticity index. Expansive soil is also known as "black cotton soil" due to its suitability for the growth of cotton. The dark color black cotton soil is believed to be either due to humus or titanium oxide. Organic matter in the form of humus makes this type of soil more plastic and compressible. Black cotton soils are clays of high plasticity. They contain mainly the clay mineral montmorillonite. The soil has high shrinkage and swelling characteristics due to this it has very low shearing strength and bearing capacity. To improve its shrinkage and swelling potential as well as its shear strength and bearing capacity many stabilization techniques has been developed through time. Soil stabilization is the process of altering properties of soil by changing the gradation through mixing with other oils or chemicals to improve the strength and durability. Some of the types of soil stabilization are cement soil stabilization, lime soil stabilization, bitumen soil stabilization, chemical soil stabilization and thermal soil stabilization [3]. In this research black cotton soil stabilization is done by using cement and coffee husk ash (CHA). The addition of cement to the soil produces a weak form of concrete, which eventually leads to the improvement of the soils strength. The quantity of cement to be added on the soil depends on many aspects like the type of soil and so on. In this project the quantity of cement is maintained at 2% to create economical condition because cement is a costly material. The other ingredient used in the stabilization process was coffee husk ash which is believed to increase the compressive strength and decrease swelling ratio and shrinkage of the soil under investigation [12]. The quantity of CHA added to the soil was using different proportion. The coffee husk was collected from Addis Ababa around Haile garment in the form of husk which was a solid waste used as a fire wood by the locals.

II. SPECIFIC OBJECTIVES

- To increase the shear strength of a soil & to control the shrink swell property of the soil
- To indicate the index property of soil samples such as liquid limit, plastic limit, plasticity index, specific gravity, maximum dry density, optimum moisture content, free swell ratio approach and related parameter of the expansive soil
- To analysis the expansive soil sample with the locally available stabilizing agent such as cement and coffee husk ash for improving their mechanical behavior
- To analyze the effects of coffee husk ash and cement on expansive soil for improving the mechanical properties.
- To determine the strength parameter of soil with different percentage of coffee husk ash and cement by conducting unconfined compression test.
- To compare the outcome of the test results and identify the changes on their physical properties.
- To suggest the most suitable stabilizing agent for strengthening the expansive soil based on the outcome of the tests conducted and make it reliable for the construction activities.
- To ascertain the most effective mechanism to enhance the maximum density and strength of soil with less free swell.
- To suggest the most suitable proportion of stabilizing agents for strengthening the expansive soil based on the outcome of the tests conducted and make it reliable for construction activities

III. MATERIALS AND METHODS

The soil samples were collected from 3 different locations at the depth of 2m below the ground level. The samples are carefully taken out of the pit and transported to the laboratory which is located in Ambo university Awaro campus. The visual examination indicates that the soil sample under investigation was black in color which mostly describes black cotton soil. The location of these three soil samples is shown in (**Table 1**).

Table 1 Sample Location of the study Area

1	Awaro campus behind geotechnical engineering lab
2	Ambo university main campus
3	Awaro campus near football ground
4	Awaro campus behind geotechnical engineering lab

a. Cement

Cement is a fine ground inorganic material which has cohesive & adhesive properties; able to bind two or more materials together into a solid mass. Cement is to react with water forming a plastic mass when the concrete is fresh and soil mass when the concrete is hard. In this study Portland pozzolanic cement was used.
Portland Pozzolanic Cement (PPC) is obtained by either intergrading a pozzolanic material with clinker and gypsum, or by blending ground pozzolanic with Portland cement. Nowadays good quality fly ash is available from Thermal Power Plants, which are processed and used in manufacturing of PPC.

b. Coffee Husk Ash (CHA)

The coffee husk was collected from Addis Ababa around Haile garment in the form of husk which was a solid waste used as a fire wood by the locals. The coffee husk ash was obtained by burning the coffee husk in an uncontrolled condition at Civil Laboratory, Awaro campus. After the completion of burning the ash was allowed to cool down for some time.

IV. RESULTS AND DISCUSSION

a. Examining the properties of natural soil:

Sieve analysis, Hydrometer analysis, Free swell test, Atterberg limit, and Compaction test were conducted for the soil samples and the result for sample-1 were shown in **(Table 2)**, **(Table 3)**, **(Table 4)**, and **(Table 5)** respectively.

Table 2 Sieve analysis for sample 1

Sieve Size	Weight retained in each Sieve (gm)	Cumulative weight of soil retained (gm)	Cumulative % of soil retained	% finer
4.75mm	68	68	3.32	96.68
2.36mm	270	338	16.49	83.51
2.00mm	96	434	21.17	78.83
1.18mm	328	762	37.17	62.83
600µ	607	1369	66.39	33.61
425µ	18	1387	67.51	32.49
300µ	255	1642	80.1	19.9
150µ	165	1807	87.85	12.15
75µ	194	2001	97.61	2.39
Pan	49	2050	100	0

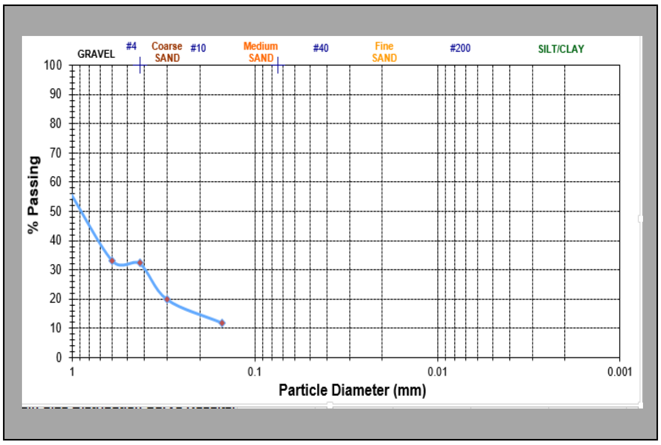

Figure 1 Particle size curve for sample-1 (Sieve analysis)

Test for the soil samples on sieve analysis (**Figure 1**)and Hydrometer analysis (**Figure 2**)and referring the standard textural triangular of IS classification system, the textural class of the soil samples were noted and classified as soil samples 1, 2 and 3 are Clay soil (C), Sandy Clay Loam (SCL) and Clay Soil (C) respectively. The percentages of gradation of soil samples obviously show that all the samples are poorly graded.

Table 3 Result on Hydrometer analysis

(t) min	(R_h^1)	R_h	H_e	$\sqrt{(H_e / t)}$	(N) $= 3.2\ R_h$	(D) mm
0.5	15	15.5	13.44	5.19	49.6	0.06
1	14.5	15	13.64	3.69	48	0.043
2	12.5	13	14.44	2.69	41.6	0.031
5	11	11.5	15.04	1.73	36.8	0.02
10	10	10.5	15.44	1.24	33.6	0.014
15	9.5	10	15.64	1.02	32	0.012
30	9	9.5	15.84	0.73	30.4	0.008
45	9	9.5	15.84	0.59	30.4	0.007

60	9	9.5	15.84	0.5	30.4	0.006
120	9	9.5	15.84	0.36	30.4	0.004

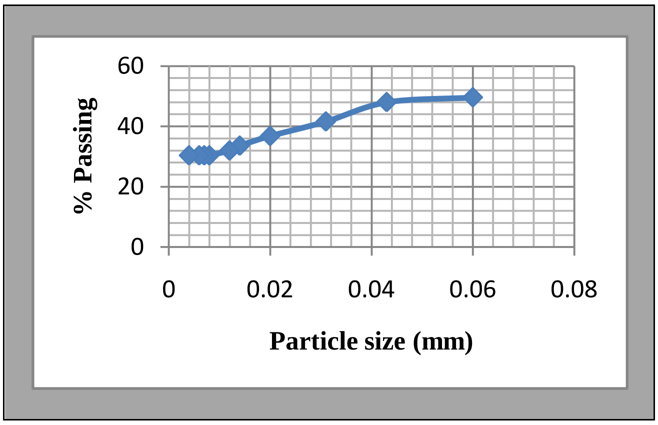

Figure 2 Curve for sedimentation analysis (S-1)

Figure 3 Test on Free swell index

Free swell index was calculated as the follow:

$$FSI\ (\%) = [(V_d - V_k) / V_k] \times 100 \quad (1)$$

Vd = Volume of the soil specimen read from the graduated cylinder containing distilled water.
Vk =Volume of the soil specimen read from the graduated cylinder containing kerosene

Table 4 Result on free swell index

Sample	Water	Kerosene	FSI
1	15	8	87.5
2	19	11	72.7
3	17.5	10	75

The free swell index of the soil samples under the investigation (**Figure 3**) are found to be 87.5%, 72.7% and 75% respectively. According to Brajesh Mishra (2015), the free swell index of black cotton soil varies between 40% and 180%. Hence, the soil samples under investigation in the current study show that the type of soil is Black Cotton Soil (BCS) [4].

Figure 4 Test on Atterberg limits

Table 5 Results of Atterberg test

Sample	Liquid limit	Plastic limit	Plasticity index (PI)
1	73	28.92	44.08
2	70.2	37.9	32.3
3	59.5	36.02	23.48

From the Atterberg test (**Figure 4**), the plastic limit of the above three soil samples is 28.92%, 37.9% and 36.02% respectively. Brajesh Mishra (2015) says the plastic limit of black cotton soil ranges from 20% to 60%. Hence, the soil samples under investigation are all black cotton soils.

Soil PI closer to 17 indicate that the soil is medium to Expansive potential; PI closer to 25 is High expansive, PI closer to 30 is highly expansive and PI close to 40 is Very high expansive potential. From Table-4, the result shows that the plasticity index of soil samples are 44.08%, 32.3% and 23.48% respectively. From this result, it is evidently clear that the soil samples are ranging from having 'high expansive potential' to 'very high expansive potential'.

Figure 5 Compaction test

From the flow curve (**Figure 6**), the liquid limit of soil sample 1 is observed as 73%. According to Brajesh Mishra (2015), the liquid limit of black cotton soil ranges between 40-120%. Therefore the soil sample under investigation is black cotton soil.

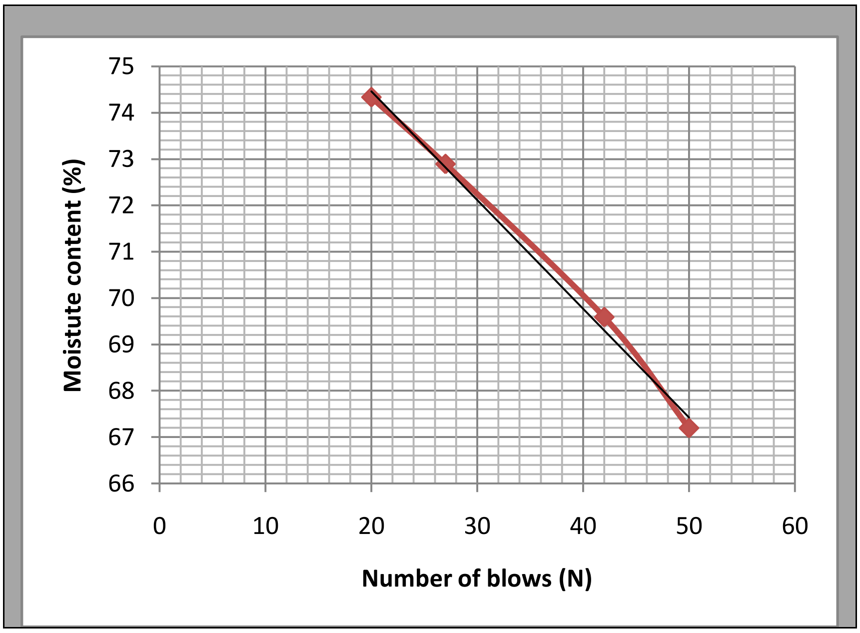

Figure 6 Flow curve soils sample-1

The standard compaction test has been conducted in the laboratory **(Figure 5)** and the results on maximum dry density and the optimum moisture content (%) for all the three samples were noted and tabulated **(Table 6)**.

Table 6 Overall result on soil samples

Percentage passing through BS no 200 Sieve	S – 1	S - 2	S – 3
Liquid limit (%)	73	70.2	59
Plastic limit (%)	28.92	37.9	36.02
Plasticity Index (%)	44.08	32.3	23.48
Free Swell (%)	87.5	72.7	75
Specific Gravity	2.66	2.56	2.61
Maximum Dry Density (gm/cc)	1.46	1.6	1.4
Optimum Moisture Content (%)	24	20	24

5.2 Soil stabilization using cement and coffee husk ash (CHA)

The stabilization of black cotton soil was done in three different trials with different proportion of cement, CHA and soil. The value of cement was kept a constant of 2% throughout the experiment for stabilization due to the economical factor. The proportions of the ingredients are shown in Table- 7 as follow.

Table 7 Proportion of ingredients

Trials	Cement (%)	CHA (%)	Soil (%)
1	2	4	94
2	2	8	90
3	2	15	83

The coffee husk ash was obtained by burning the coffee husk in an uncontrolled condition (**Figure 7**). After the completion of burning the ash was allowed to cool down for some time then it was crushed and sieved through 0.425mm sieve (**Figure 8**) to proceed on the tests. The coffee husk ash was black in color.

Figure 7 *Preparation of Coffee Husk Ash (CHA)*

After preparing the ingredients and mixing those with the previous tests like Atterberg limit and compaction tests were done by following the same procedure.

Figure 8 *Mixing of Ingredients*

The following table compares the result of tests done on natural soil and stabilized soil with different proportion of ingredients.

Table 8 Comparison of the results on soil samples with special ingredients

Percentage passing through BS no 200 Sieve	Natural soil	T- 1	T- 2	T- 3
Liquid limit (%)	73	78.2	90.97	84.6
Plastic limit (%)	28.92	43.6	62.2	75.6
Plasticity Index (%)	44.08	34.6	28.77	8.9
Free Swell (%)	87.5	77.3	38.46	17.86
Maximum Dry Density (gm/cc)	1.46	1.5	1.52	1.56
Optimum Moisture Content (%)	24	24	22	18

As the percentage of stabilization agents increase the plasticity index, free swell index and optimum moisture content decreases and the maximum dry density increases. This implies that the stabilized soil has higher strength and lower shrinkage than the natural soil which is similar with the statement given in the previous study of Brajesh Mishra, 2015.

V. CONCLUSIONS

In the central region of Ambo, the black cotton soils are spread over extensive area; posing serious problems to the civil engineering structures. Based on the observation from the tests which was conducted, the following conclusions have been reached:-

1. The results of sieve analysis for the soil samples shows that the soil samples are not uniform, and the most of the samples are poorly graded.
2. The results obtained in this investigation so far; (Atterberg, sieve analysis, hydrometer analysis, specific gravity and compaction test) shows that the soil samples in the study area are not uniform, as some of the soil samples are having more clay content, more compactness, and plastic, hence the menace of unsuitability for the construction.
3. The specific gravity of the soil samples were determined using the density bottle of 200cc shows that the range varies between 2.56 and 2.66. Hence the type of soil samples was found to be BCS.
4. The black cotton soils are characterized by their alternate swelling and shrinkage leading to the changes in their volume, which are often large enough to seriously damage and cause cracking of civil engineering structures.
5. The soil samples under investigation have very high plasticity and swelling potential. Hence, further improvement of the soil is needed.
6. Having identified the degree of swelling potential and the problematic nature of these soils , a task was undertaken to investigate the possibility of improving the engineering properties of these soils so that, a better understanding is facilitated for the civil engineering practitioners, while dealing with these soils.
7. Considering the proximity and availability aspects cement and coffee husk ash were chosen to be used for the task, as a stabilizer of black cotton soil.
8. The characterization of the index and grain size properties is quite useful for the civil engineers in having a fair and quick assessment of the engineering behavior of the soils without engaging into the elaborate and time consuming test procedures for determining the engineering properties of the soils.

9. The stabilization process improved the Maximum dry density (MDD) from 1.46g/cc to 1.58g/cc and decreases the Optimum moisture content (OMC) from 24% to 18% respectively.
10. During the stabilization process, three trials were performed. From the results, it is observed that stabilization using 2% cement and 15% CHA is the best stabilizer so far.

Recommendation
The stabilization process in the current study was done with minimum number of trials due to the time restriction. So it is recommended that to achieve the better improvement on the soil, it is advisable to perform with maximum number of trials with different proportions of ingredients.

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