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Investigating erosion resistance of expansive clay soils stabilised with brick powder waste mixed with sulphonated oil for unpaved roads

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ABSTRACT

Gravel roads with expansive soils have a property of swelling and shrinkage due to changes in moisture regime which reduces bearing strength. Engineers often cut and replace with a suitable material or stabilize using lime or cement. However, the cost of adding these additives has tremendously increased in the past few years; therefore, a need for a cost-effective stabilization material. Erosion resistance of expansive clay soils stabilized with Brick Powder waste mixed with Sulphonated Oil for unpaved roads was investigated. The native soil used in this study was classified as A-7-6 (clayey soil) according to ASTM D3282-93 and it was observed not to meet the performance requirements for the unpaved roads. Brick powder waste was from burnt clay bricks largely produced in Uganda mixed with the native soil in proportions between 30% and 50% at an interval of 10%. The optimum dosage with brick powder was then improved with sulphonated oil dosage levels of 0.25-1.25% at 0.25% intervals by weight. Improvements were noted in the properties of the expansive clay soil with optimum values being realized at 50% brick powder and 1% sulphonated oil by weight. The plasticity index reduced by about 35% with Maximum Dry Density (MDD) of the native sample improved by about 11.86% on addition of 50% brick powder and further improvement by about 5.46% on addition of 1.00% sulphonated oil. The OMC reduced to about 41.29% on addition of brick powder and further reduction by about 11.01% on addition of sulphonated oil. CBR value improved from 6.4% to 17.6% on addition of 50% brick powder and 1.00% sulphonated oil. The improved sample showed a UCS value of 0.53 MPa for soaked and 0.64 MPa for un soaked sample. The erosion resistance of the sample was about 70.4% of the samples stabilized with both 50% brick powder and 1.00% sulphonated oil.

Keywords: Erosion resistance, Expansive clay, Brick powder, Sulphonated oil, Durability

1 INTRODUCTION

Gravel Road maintenance is essential to preserve the unpaved road in its original constructed condition, ensure user safety and ensure convenient travel times along the route as well as contributes to reliable transport at reduced cost as there is a direct link between road condition and vehicle operating costs. An improperly maintained road represents an increased safety hazard to the user, leading to more accidents and losses to the economy since people and goods spend much time and money in transit (Ministry of Works, Housing and Communications, 2004). Over the years, the government has tried to carry out periodic maintenance of gravel roads, however there are reports and persistent public outcry about the poor state of these unpaved roads and the deteriorating quality of works being executed. Most construction works in most developing countries involve the use of soil materials for foundation. Some of these soil materials when encountered on site may not be directly suitable for use due to their poor strength characteristics (Makusa, 2013), and when such occurs, the engineer is left with the choice of borrowing suitable materials from other sites or improves on the strength of the available ones. When materials are imported to the site, the cost of construction becomes high due to delay in construction, increased cost, and time wastage and most of the times scarcity of a better material (gravel). The engineer then has to add stabilizing agents to improve the properties of the available soil on site using various means of soil improvement techniques (Vastrad et al., 2020). Stretches of gravel roads with expansive soils are a problem in the maintenance as they deteriorate faster and thus an increase in the number of times they are maintained as well as costs. Expansive clay soils are soils that expand when hydrated and shrink when dry and this is due to the presence of swelling minerals such as montmorillonite and smectite (Guggenheim & Martin, 1995). This expansion and shrinkage lead to pressure being exerted to buildings, pipelines, roads causing them to crack and experience extensive deterioration (Bhavsar & Patel, 2014).

The study focused on the use of burnt brick powder mixed with sulphonated oil (SO) to improve the durability of expansive clay soil in a cost-effective way during gravel road maintenance by improving erosion resistance of the unpaved roads. Sulphonated oil is obtained by treating fatty oils with concentrated Sulphuric acid through sulphonation process. SO has a hydrophobic component and acts as a lubricant that reduces the surface tension of water during compaction. SO is commercially available & claimed to be economic, user friendly, and sustainable as a soil stabilizer (Hiratsuka et al., 2007).

2 MATERIALS AND METHODS

2.1 Expansive clay soil

Clay soil was obtained from a stretch of road at Ch. 0+100 km and Ch. 0+200 km in Nyeihanga, Rwampara District. It was obtained by open excavation at a depth of 1.0-1.5 meters below the ground level (TMH1, 1986). Marks were placed on them to indicate soil descriptions, sampling depths and dates of sampling. The samples were taken to the laboratory and spread on different matting to facilitate air drying. All the clods and lumps in the samples were broken down and reduced to fine particles before performing Atterberg limits, MDD and CBR. The properties of the soil are indicated in Table 1.

Table 1. *Properties of expansive clay soil*

Parameters	Results	Specifications
Liquid limit (%)	43	< 41%
Plastic limit (%)	16.8	< 25%
Plastic index (%)	26.2	< 30%
Linear shrinkage	8.6	
Percentage passing BS sieve 200 (%)	86.4	
AASHTO classification	A-7-6	
OMC (%)	20.1	
MDD (kg/m^3)	1.636	
CBR at 95% of MDD (after 4 days of soaking)	6.4	> 7.0

2.2 Brick powder (BP)

Brick powder is a non-plastic waste that is found near commercial brick kilns out of the crushed bricks in rural areas, and a waste from buildings (Neha & Trivedi, 2017). BP is readily available as a waste in many commercial kilns and construction business (Srikanth Reddy et al., 2018). Bricks were obtained from Nsangi Clays Limited located along Masaka road and crushed manually to obtain the powder. The powder was then subjected to particle size distribution (PSD) in accordance to ASTM C618 specifications. Close observations showed that the grains had a semi-oval shape and semi-smooth surface (Aliabdo & Hassan, 2014). The brick powder was 85.8% sand and 14.2% fine grained as revealed from the sieve analysis test.

2.3 Sulphonated oil (SO)

Sulphonated oil is obtained by treating fatty oils with concentrated sulphuric acid through sulphonation process (Mensah et al., 2018). SO has a hydrophobic component and also acts as a lubricant that reduces the surface tension of water during compaction. SO is commercially available and, user friendly, and sustainable as a soil stabilizer (Hiratsuka et al., 2007; Alhassan & Chukwuma, 2013). The sulphonated petroleum product (SPP) was obtained from Chemical Industries Limited with product name ISS 2500 Chemical stabilizer along the 6th and 7th streets in Kampala industrial area. SPP was taken in the laboratory under proper guidance by the manufacturer on how to use and act as a lubricating agent. SO was added to the blend of clay and brick powder soils (50% clay soil and 50% brick powder). The properties of sulphonated oil are shown in Table 2.

Table 2. *Properties of sulphonated oil*

Property	Content
Specific gravity, G_s	1.05
Molecular weight, *M* (gr/mol)	380
Physical state	Highly viscous liquid
Appearance	Reddish Brown
Odor	Slightly pungent
Solubility in water (at 20 °C)	100%
Flammability	Non-flammable
Vapour pressure (mmHg)	20
Freezing point (°C)	−10
Boiling point (°C)	100
Acidity, pH	3.10
Chemical formulation	$r{-}(So_2)oH^-$

2.4 Sample preparation

The samples for laboratory testing were prepared in accordance with BS 1377 Part1:1990. On account of the fact that some tropical soils are sensitive to pre-test drying methods, air-drying was undertaken. Other pre-test sample preparation methods included pulverization, sieving and sub-sampling (coning, quartering and riffling). After air-drying, index properties tests were carried out for classification.

In order to study the effect of brick powder and sulphonated oil on the properties of expansive clay soils, specimens with specified amounts of BP, SO and soil were prepared in different mixes; Mix I (100% soil, 0% BP, 0% SO), Mix II (50% soil, 50% BP, 0% SO), Mix III (50% soil, 49.75% BP, 0.25% SO), Mix IV (50% soil, 49.5% BP, 0.5% SO), Mix V (50% soil, 49.25% BP, 0.75% SO), Mix VI (50% soil, 49.00% BP, 1.00% SO) and Mix VII (50% soil, 48.75% BP, 1.25% SO). Most specifying bodies permit the use of recycled materials as a portion of the road layers. According to BS 6543 for waste materials and industrial by-products, a maximum of 50% brick powder by weight of total mass could be used. The mixing was done mechanically on a metal tray. For consistency, soil was mechanically blended before mixing with BP and SO. Tests of physical properties of the different blends/mixes were conducted.

2.5 Tests

The following tests were carried out on the prepared specimens:

- Atterberg limits test in accordance with BS 1377: Part2:1990.
- Proctor compaction test in accordance with BS 1377: Part4:1990 for natural soil and BS 1924: Part2:1990 for stabilized soil.
- California Bearing Ratio test in accordance with BS 1377: Part4:1990 for natural soil and BS 1924: Part2:1990 for stabilized soil.
- Unconfined Compression test in accordance with TMH1: Method A14: 1986

2.6 Erosion resistance test

The test was carried out according to ASTM G76-95. The stabilized samples (50% BP and 1.00% SO) were subjected to erosion resistance tests using experimental setups as shown in Figure 1. This was to determine the percentage particle loss to be achieved in relation to water erosion of unpaved roads. The main aim was to simulate the erosion resistance potential of the material by comparing the amount of material loss from the un-stabilized and stabilized samples. This test helped to determine the capacity of sulphonated oil in protecting the compacted specimen from water flow. The stabilized sample will last longer on the road after being exposed to different weather conditions mostly rain. Water being the number one enemy of the road structure, it is very essential to establish the behaviour of a sample after being exposed to rain.

The sample was compacted in the mould at optimum moisture content, then extruded gently and left to dry until a constant mass is reached and recorded. It was placed into the erosion resistance apparatus set up. The steady water supply pipe is connected to the jet with holes of different diameter spaced at 1mm interval to represent a suitable water force that would initiate erosion (Range & Horak, 2005). The diameters range between 1 -2 mm to represent a typical rain drop. The compacted sample was placed in front of the jet at 90-115mm to minimize decrease in velocity of the water contacting the specimen. The whole set up is oriented at an angle of 350 to allow for the runoff of water and eroded soil (Range & Horak, 2005). The sample was jet for 5 minutes to have sufficient time for erosion and then allowed to drain for 5 more minutes. It was then dried in an oven to a constant mass and the mass loss as a percentage to the original mass recorded.

Figure 1. *Erosion resistance setup*

3 RESULTS AND DISCUSSION

3.1 Atterberg limits

Stabilization of the fine-grained soil using brick powder decreased the liquid limit of the neat sample from 43 to 29.4 on the addition of 50% BP as seen in Table 3. This is due to the reduction of clay particles and an increase of the BP which is a coarser material and Non-Plastic (Ash-Shu'ara & Wale, 2018). This reduction in liquid limit implies that the soils ability to retain moisture decreases with increasing BP content up to 50% and is considered an improvement to the engineering properties of the soil since this reduces the soils ability to retain water thus reducing the shrinking tendencies of the soil that may lead to cracking.

The combined effect of SO is noted to cause a slight reduction in the Atterberg's limits of the BP stabilized expansive clay soil, Table 3. The decrease in the Atterberg's limits is attributed to the adsorption of one part of molecule of SO onto the surface of the clay particles (i.e. the negatively charged hydrophilic head of SO attracts the positive cations present in the vicinity of the negatively charged clay surface) & reduces its ion exchange capacity which results into the inability of clay mineral to absorb water, thus changing it from hydrophilic to hydrophobic in character or water repellent. The reduction in plasticity index causes a significant decrease in swelling and shrinking potential and this implies an increase in workability of the soil.

Table 3. *Properties of stabilized soil*

Description/Mix	Atterberg Limits			Compaction Parameters		Soaked CBR (%)	UCS (MPa)	
	LL (%)	PL (%)	PI (%)	MDD (kg/m^3)	OMC (%)	95 (%)	Soaked	Unsoaked
Neat clay	43	16.8	26.2	1636	20.1	6.4	-	-
50% soil, 50% BP, 0%SO	29.4	12.3	17.1	1830	11.8	16.5	-	-
50% soil, 49.75% BP, 0.25%SO	29.0	12.2	16.8	1850	11.3	-	0.26	0.29
50% soil, 49.5% BP, 0.5%SO	28.8	12.1	16.7	1872	11.2	-	0.29	0.33
50% soil, 49.25% BP, 0.75%SO	28.3	11.9	16.4	1898	10.9	-	0.37	0.44
50% soil, 49.0% BP, 1.0%SO %	27.3	11.4	15.9	1930	10.7	-	0.53	0.64
50% soil, 48.75% BP, 1.25%SO	27.1	11.3	15.8	1938	10.5	17.6	0.48	0.51

3.2 Maximum Dry Density (MDD) and Optimum Moisture Content (OMC)

The native soil had an OMC of 20.1% that decreased to 11.8% on addition of 50% BP. This is due to a reduction in surface area of the soil. The native soil of clay has more fines than the material being added which is BP with coarser material thus reducing the surface area. Materials with fine particles have larger surface area and in order to completely mix with water, they will take in a lot of water compared to a coarser material that has a smaller surface area.

On addition of BP, the MDD of the native sample increased from 1636 kg/m^3 to 1830 kg/m^3 at 50% BP. This is as the result of reduction in surface area of the clay soil and being replaced by a coarser material that has a low surface area and therefore requires less water for compaction. In the end, there is proper compaction of the soil sample hence attaining higher maximum dry density (Vinay & Hemanth, 2015).

The maximum dry density increased at a decreasing OMC on addition of different percentages of SO. At 0.25% addition of SO, a 1.1 % increase in MDD from 1830 kg/m^3 to 1850 kg/m^3 and the OMC decreased from 11.8% to 11.3% and continuously following an increasing rate. The increase in the MDD was attributed to the reduction of surface tension of water (Hiratsuka et al., 2007). The surface tension of water helps the particles to attract to each other and therefore higher stress to separate the water-water attraction. Therefore, due to the hydrophobic tail component of SO that reduces the surface tension of water, less effort will be needed to mix the water and SO with the best blend and thus having a compacted material with higher MDD (TRL & Page-Green, 2003). However, an insignificant percentage decrease is observed between the addition of 1% and 1.25% SO where the increase was at 0.4%. The significant MDD was obtained between 0.25% and 1%. Beyond these percentages there was a slight percentage increase of MDD due to high accumulation of high viscous pore fluid and this in turn makes the stabilized sample particles to over slide and thus contribute less or no impact. This is because the soil becomes very hard to compact hence lower strength percentage increase attained (Moloisane & Visser, 2014).

3.3 California Bearing Ration (CBR)

On addition of BP, there was introduction of a coarser material and this led to an increase in CBR from 6.4 to 16.5 at 95% MDD at 50% BP. The increase in CBR was due to the addition of the coarser (Joshi et al., 1994) material which consequently led to an increase in the internal friction between the soil particles. This was also due to a higher bearing strength and specific gravity of the BP additive and thus the increase up to the required standard of G15 (Vastrad et al., 2020). The CBR value obtained at 1.25% addition of SO showed a slight increase in the CBR value. The slight increase is attributed to the improvement in the MDD. The penetrative strength of the subgrade layer obtained of 17.6 is highly acceptable as per the Ministry of works and transport and therefore good for use as a subgrade material.

3.4 Unconfined Compressive Strength (UCS)

Cylindrical specimens used for the experiments were 105 mm diameter and 127 mm height. The samples used for the UCS tests were at their optimum moisture contents. After compaction, the samples were sealed tightly using a plastic sheet to prevent loss of moisture content. All the treated samples were subjected to cure at room humidity and room temperature of 25 ± 2°C for 7 days before testing. The soaked samples were immersed in water for 4 hours after the curing period before testing. There was an increase in the UCS values with additional content of SO from 0.25% to 1.0%. This was followed by a decrease in the UCS values with more SO percentages. The UCS (unsoaked) value increased from 0.29 MPa at 0.25% SO to 0.64 MPa at 1% SO. Likewise, UCS (soaked) rose from 0.26 MPa at 0.25% to 0.53 MPa at 1% SO. This may be attributed to cation exchange reaction in which the sulphonated oil changes the soil texture with the clay particles. The UCS reduced from 0.53 MPa to 0.48 MPa, and 0.64 MPa to 0.51 MPa for soaked and unsoaked specimens respectively with SO content increased from 1% to 1.25%. This is portrayed by pore-fluid viscosity where it is high enough to offset the positive contribution offered by physiochemical interactions and thus a reduction in strength and stiffness compared to lower SO percentages (Soltani et al., 2019b). The increase in UCS values is attributed to the dominant role portrayed by physicochemical interactions in promoting a flocculated soil fabric because of a decreased double layer thickness.

Apart from the UCS, all the other properties of the soil increased with additional percentages of SO up to 1.25%. Therefore, the mix with the highest UCS value was taken as the optimum mix. This corresponded to the mix of 50% soil, 49% BP, 1% SO.

3.5 Erosion resistance

The different samples were subjected to jetting. The sample was jet for 5 minutes to have sufficient time for erosion and then allowed to drain for 5 more minutes. The mass before and after jetting was determined. This was done in order to determine the percentage soil loss. The neat sample after compaction had the highest particle loss of 27.9% of which is in the region of being highly erodible (Range & Horak, 2005). With the addition of BP, the particles loss reduced to 22% but still highly erodible. The greater decrease is observed on addition of SO with the greatest decrease at 6.7% of particle loss at 1.25% SO. The optimum SO additive was at 1.00% and therefore the particle loss obtained is 7.6% which lies in the region of being less erodible when exposed to the weather conditions.

Table 4. *Erosion resistance results*

Description/Mix	Dry density (kg/m^3)	Weight before (W_b/g)	Dry weight per cycle (g) (6 wetting-drying cycles)						Material loss (%)
			W1	W2	W3	W4	W5	W6	
Neat clay	1636	4165	3935.4	3704	3476	3246.1	3016.7	3003.9	27.9
50% soil, 50% BP, 0%SO	1830	4337.8	4147.8	3962.4	3773.5	3609.8	3419.6	3383.5	22.0
50% soil, 49.75% BP, 0.25%SO	1850	4362.4	4202.6	4045.8	3890.9	3730.3	3570.4	3551	18.6
50% soil, 49.5% BP, 0.5%SO	1872	4409.3	4285.7	4165	4042.4	3923.7	3801	3783.2	14.2
50% soil, 49.25% BP, 0.75%SO	1898	4461.6	4372	4285.7	4193.4	4107.9	4017	3984.2	10.7
50% soil, 49.0% BP, 1.0%SO %	1930	4525.7	4456.9	4392	4324	4263.7	4199.6	4181.7	7.6
50% soil, 48.75% BP, 1.25%SO	1938	4537.3	4477	4419.1	4357	4295	4242.8	4233	6.7

4 CONCLUSIONS

- The research was aimed at stabilizing clay soils with a combination of Brick Powder and Sulphonated oil for use as improved subgrade of unpaved roads. From the classification tests, the soil sample was classified as A-7-5 consisting of 86.4% fine materials,13.5% sand and 0.1% coarse material.

- The neat sample had a CBR of 6.4% at 95% compaction, PI of 17 %. The CBR values did not meet the requirements for use as improved subgrade based on the General Specifications for roads and Bridges which specify a minimum CBR value of 15%. The sample exceeded the minimum PI and LL of 25% and 41% respectively and is considered a poor subgrade material suitable for stabilization to be used on road construction.
- The MDD increased with increasing BP content from 1636 kg/m^3 for the neat sample to 1830 kg/m^3 at 50% BP content. The MDD further increased after addition of SO to 1930 kg/m^3 at 1% SO. The OMC decreased with increase in BP content from 20.1% for the neat sample to 11.8% at 50% BP content. Further addition of SO led to attainment of OMC of 10.7 %.
- The CBR increased at all compactive efforts with an optimum value achieved at 50% BP and 1.00% Sulphonated oil content of 17.6%.
- Addition of SO into the 50% BP realized a less percentage in particle loss of 7.6% at 1.00% SO as compared to about 27.9% of the neat soil. This means that the material saved from being lost is about 70.4% as compared to the material loss of un-stablished sample.
- The soil sample containing 50% BP and 1.00% SO gave the highest CBR value of 17.6% at 95% compaction and UCS value of 0.64MPa and qualifies for use as improved upper subgrade for unpaved roads.

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