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Effects of Soldier-Ant Mound (SAM) on the Strength Characteristics of Lateritic Clay Soils

A. O. Ogundalu[1*], A. O. Adeboje[1] and F. Adelaja[1]

[1]*Civil Engineering Department, University of Lagos, Nigeria.*

Authors' contributions

This work was carried out in collaboration between all authors. Author AOO designed the study, performed the analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Author AOA managed parts of the analyses of the study and literature searches. Author FA collected the SAM materials and carried out the experimental investigations. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

The aim of this work is to investigate the effect of Soldier-Ant Mound (SAM) on the strength characteristics of lateritic clay soils in order to improve their poor geotechnical properties for road pavement construction. Three soil samples were collected from a burrow pit along the Lagos-Ibadan Expressway, Lagos, Nigeria. The samples were mixed with Soldier-Ant Mound in various proportions (0%, 2%, 4%, 6%, 8% and10% by weight) and subjected to soil strength tests: Compaction tests, California Bearing Ratio (CBR) and Unconfined Compressive Strength tests at the University of Lagos, Nigeria between June 2012 and July 2013. Results obtained were compared with the natural soil and standard values. The Atomic Absorption Spectroscopy, AAS, gave the exchangeable cations present in the Soldier-Ant Mound as: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potassium (K^{+}) and Aluminium (Al^{3+}). The plasticity index decreased with increase in SAM content which signifies a reduction in any swelling and deformation that may take place. The maximum dry density, soaked CBR and Unconfined Compressive Strength all increased with increase in SAM content. The addition of 10% SAM content reduced the plasticity index by 7.5% (from 25.8% to 23.9%) and increased the maximum dry density of the clay soil from 1660kg/m^3 to 1750kg/m^3 which is considered satisfactory to excellent. The Optimum moisture content of the clay soil was reduced by about 15%. The addition of 10% SAM increased the soaked CBR by 85% (from 10.43% to 19.35%) while the unconfined compressive strength of the Lateritic Clay Soil increased by 122% (from

**Corresponding author: E-mail: waleogundalu2008@gmail.com;*

40.32kN/m^2 to 89.36kN/m^2). Soldier-Ant Mound significantly improved the engineering properties of Lateritic Clay Soil. The results indicate that there is a potential in the use of Soldier-Ant Mound for improving the strength characteristics of lateritic soils for road pavement construction and other earth works.

Keywords: Soldier-ant mound; lateritic clay soils; strength characteristics; California bearing ratio.

1. INTRODUCTION

Lateritic clay soils cover large areas of the African, South American and the Australian shields. Lateritic clay soils refer to highly weathered soils formed from materials with lower concentrations of oxides or hydroxides of iron and aluminum [1]. Laterite is igneous rocks tropically weathered in-situ which has decomposed partially or totally with a concentration of iron and aluminum sesquioxides at the expense of silica [2]. Laterization is favored by a warm climate with alternating wet and dry seasons as is common in the tropics, [3].

As a result of their availability and low cost, lateritic soils are widely used materials for road pavement construction works and for various earthwork projects in most countries in the tropics like Nigeria [4,5]. Most lateritic clay soils in their natural states have poor engineering properties exhibiting swelling properties, high plasticity, low strength and loss of strength in the presence of water [6,7]. Failures of highway pavements are common on the Nigerian highway system, [8]. The failures have been attributed to poor geotechnical properties of the underlying soils (mostly lateritic clay soils) which constitute the base or sub grade material for the entire road configuration [9].

Various efforts have been made to stabilize and improve the engineering properties of lateritic clay soils with cement, lime, admixtures, bentonite and waste products for engineering works [10,11]. Though the use of cement appears to be efficient, the cost of stabilizing with cement is expensive and requires huge foreign exchange which is scarce in developing countries. Hence researches have focused on potentially cost effective materials, admixtures and waste products like fly ash, rice husk ash and marble dust that can improve the properties of soil [12-15].

The strength of compacted lateritic soil-bentonite mixture for use as landfill liner and cover was evaluated [16]. Results show that the stepped incorporation of bentonite resulted in increased plasticity index and optimum moisture content while the maximum dry density and unconfined compressive strength of the compacted mixture reduced with higher bentonite content.

The effects of Rock Flour on some engineering properties of lateritic soil was investigated, [17]. It was concluded that linear shrinkage, Atterberg limits, optimum moisture content and un-soaked CBR of the studied soil were improved by addition of rock flour. However, the addition of more than 4% of rock flour by weight of soil causes negative influence on the engineering properties of the soil.

While Soldier-Ant Mound have been observed to be very stable and sound under various weather conditions from very harsh to extreme rainfall and heat, no research findings have been reported on the effect of Soldier-Ant Mound (SAM) on lateritic clay soils. The strength characteristics of concrete beams with cement partially replaced by Uncalcinated Soldier-Ant

Mound Clay (SAMC) was evaluated [18]. It was reported that all the chemical components of SAMC conformed to the requirements of American Society for Testing and Materials Specifications for Pozzolanas [19]. He further reported that the addition of SAMC accelerated the setting time of the cement paste, increased the flexural strength of concrete but reduced the densities and compressive strength of the concrete.

It is therefore the aim of this work to investigate the effect of Soldier-Ant Mound (SAM) on the strength characteristics of lateritic clay soils in order to improve the engineering properties of lateritic clay soils and the quality and standard of road works in Nigeria and other countries in the tropics. Though there is no record of the quantity of Soldier-Ant Mound deposit in Nigeria, the chemical composition has been analyzed. The possibility of manufacturing Soldier-Ant Mound or a similar material of same chemical composition as stabilizer is a subject of future investigation.

2. MATERIALS AND METHODS

2.1 Lateritic Clay Soil Samples

The Lateritic clay soils were collected at a burrow pit at Orilowo village, 48Km from Lagos along the Lagos-Ibadan Expressway on Latitude 6º5.431'N and Longitude 3º32.437'E at an elevation of 29m. This is a major borrow pit for the quarrying of laterite for road pavement construction. The soils used in the study are reddish clay soils classified as A-7-6 in the AASHTO Soil Classification System [20] and CL in the United Soil Classification System [21].

2.2 Soldier-Ant Mound

The soldier-ant mound material used was collected from a heap of soldier-ant mound at the Lagoon front area of the University of Lagos. The soldier-ant mound was ground into fine powder and mixed with the Lateritic clay soil in various proportions (0%, 2%, 4%, 6%, 8% and10% by weight).

2.3 Methods

Tests involving moisture-density relationship, CBR and Unconfined compression were carried out using air dried samples ground into powder. The lateritic clay soil samples were then mixed with Soldier-Ant Mound in various proportions before each test.

2.3.1 Determination of chemical composition by atomic absorption spectroscopy (AAS)

Atomic Absorption Spectroscopy, AAS, was carried out on the soil samples at the Chemistry department, University of Lagos, Nigeria to determine the chemical composition of the soil sample and the Soldier-Ant Mound. A summary of the chemical composition of the lateritic clay soil and soldier-ant mound (SAM) is presented below Table 1. Atomic absorption spectroscopy (AAS) is a spectro analytical procedure for the quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state.

Table 1. Cation exchange capacity (CEC) (mg/100g)

Sample	PH	Fe_2O_3	Al	Fe	Ca	Mg	K	SiO_3	Na^+	Mg^{2+}	K^+	Ca^{2+}
Laterite	6.4	0.40	0.40	20.50	1.23	0.70	0.44	61.20	0.06	0.002	0.003	0.007
SAM	6.3	0.96	0.20	18.70	1.44	1.12	0.39	55.20	0.08	0.001	0.002	0.003

2.3.2 Soil index properties

Fresh soil samples collected and tested within 3 months were used in order to prevent alteration of the properties of the residual soil. All the samples were air-dried for 1-day before testing in order to simulate field conditions as suggested by Peck [22]. Laboratory tests were performed on the samples in accordance with British Standard, BS 1377 [23] for the natural soil and BS 1924 [24] for the treated soil. A summary of the soil index properties carried out at the Soil Mechanics Laboratory, University of Lagos, Nigeria is presented below Table 2.

2.3.3 Compaction tests

Tests involving the compaction tests and strength tests of CBR and Unconfined compressive strength were carried out using the West African Standard (WAS) energy levels. If the BS (Proctor) compaction mould is used, the compactive effort for the WAS consists of the energy derived from a 4.5kg rammer falling through 45cm onto five layers, each receiving 10 blows. When the CBR mould is used, the WAS compactive effort is also derived from a 4.5kg receiving 25 blows [25]. WAS compaction is commonly used in West Africa region.

2.3.4 California bearing ratio (CBR) tests

Two tests of CBR tests were conducted on each soil sample, one at the Optimum Moisture content, compacted to the Maximum Dry Density (as per the West African Standard of Compaction) and the other test on a similarly compacted under soaked conditions. A four-day soaking period was adopted. During soaking of the sample, the swelling potential was also measured.

3. RESULTS AND DISCUSSION

3.1 Chemical Composition

The result of the chemical analysis by Atomic Absorption Spectroscopy is presented below Table 1. The main oxides present in the Lateritic clay soil sample and the Soldier-Ant Mound (SAM) is Silicon Oxide (S_IO_2) and Iron oxide. Clay particles attract and absorb cations from water molecules and other solutions to balance negative charge on their surfaces. The cations are called exchangeable cations because a group of one type of cations can be replaced by another group of different cations having the same total charge. The exchangeable cations present in the Soldier-Ant Mound are: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), Ferrous (Fe^{3+}) and Aluminium (Al^{3+}). Hence the mechanism of stabilization will not be similar to that of lime which depends on a Cation exchange with Calcium Oxide.

3.2 Index Properties of Natural Soil and Soil-SAM Mixture

The Index properties of the soil sample and the soil/soldier-ant mound mixture (at 0%, 2%, 4%, 6%, 8% and 10% by weight content) are summarised Table 2. Classification test indicates that the lateritic soil sample and the soil-SAM mixture all lie above the A-line Fig. 1 and can be classified as A-7-6 soil under the AASHTO Soil Classification System [20] or CH in the United Soil Classification System, [21]. The soil is inorganic clay with high plasticity.

Table 2. Index properties of natural soil sample and soil-SAM mixture

Soil property	Soldier-Ant mound content (%)					
	0%	**2%**	**4%**	**6%**	**8%**	**10%**
Liquid Limit (%)	48	47	46.5	46	45.7	45
Plastic Limit (%)	22.2	21.8	21.5	21.3	21.2	21.1
Plasticity Index (%)	25.8	25.2	25.0	24.7	24.5	23.9
Maximum Dry Density, (Kg/m^3)	1660	1690	1710	1720	1740	1750
Optimum Moisture Content (%)	20.8	19.50	18.40	18.00	17.9	17.70
Soaked CBR (%)	10.43	12.53	14.20	16.38	18.63	19.35
Swelling Potential (%)	0.0812	0.0797	0.0782	0.0767	0.0752	0.0722
Unconfined Compressive Strength (KN/m^2)	40.32	50.20	65.39	75.45	81.49	89.36

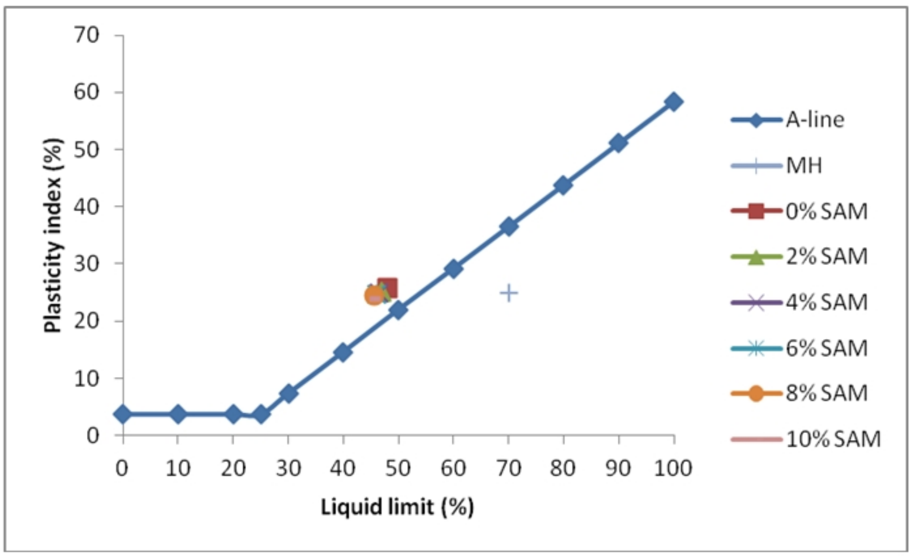

Fig. 1. Plasticity chart for soil classification

3.3 Effect of Soldier-Ant Mound on Soil Index Properties (Atterberg Limits)

The addition of SAM to the lateritic clay soil led to a decrease in the liquid limit and plastic limit of the clay soil Fig. 2. In addition, the plasticity index of the soil-SAM mixture decreased with increase in soldier-ant mound content. The plasticity index decreased from 25.8% to 23.9% at a SAM content of 10%. The decrease in the plasticity index on addition of soldier-ant mound signifies a reduction in any swelling which may occur. This is a good impact on the geotechnical properties of the soil sample as road deformation due to swelling will reduce.

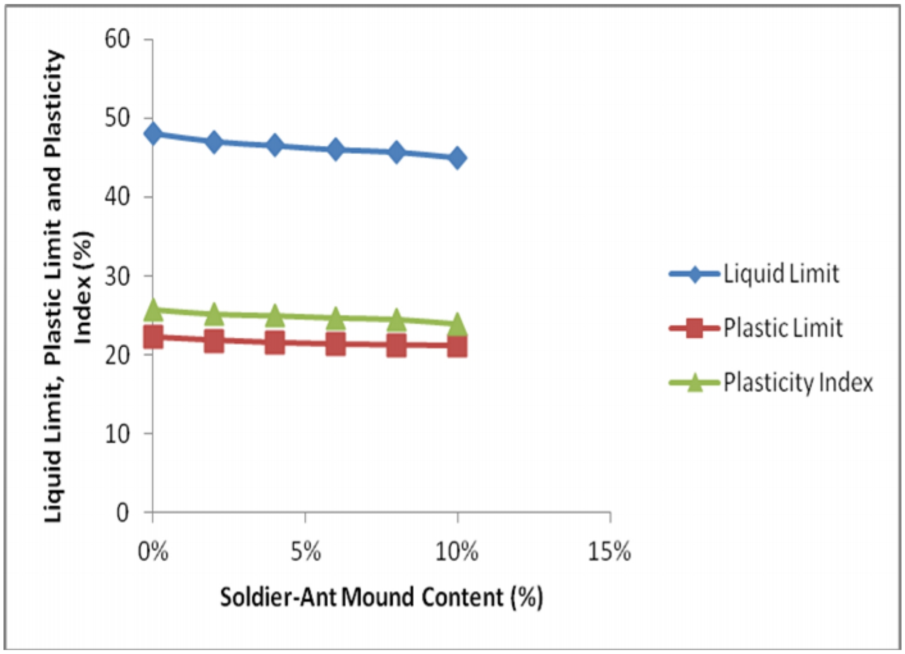

Fig. 2. Variation of liquid limit, plastic limit and plasticity index with soldier-ant mound content

3.4 Effect of Soldier-Ant Mound on the Compaction Characteristics

The effect of Soldier-Ant Mound (SAM) content on the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil for the West Africa Standard (WAS) compactive efforts are shown below Fig. 3. The MDD of the lateritic clay soil-SAM mixture increased with increase in SAM content Fig. 4, while the OMC decreased with increase in SAM content Fig. 5. The results show that Soldier-Ant Mound decreased the optimum moisture content, OMC, while increasing the maximum dry density, MDD. This trend is opposite the effect of lime on clayey soils as lime usually reduces the MDD and increases the OMC of clayey soils at a given compactive effort, [12]. The result may be due to the presence of high quantity of Iron and Ferrous oxide in the Soldier-Ant Mound which acts as a cementing agent Table 1. The MDD of the lateritic clay soil is about 1660Kg/m^3. The addition of 10% SAM to the lateritic clay soil increased the MDD of the soil samples by about by 5.4% from 1660kg/m^3 to 1750kg/m^3. The MDD obtained with the addition of SAM fall within the range of 1720 to 1920kg/m^3 which is considered satisfactory to excellent. The increase in the MDD may be due to the specific gravity of the SAM which is higher than that of the clay soil. The OMC of the natural soil was reduced by about 15% at 10% SAM content. The decrease in the OMC can be attributed to the cation exchange between the soil and the SAM and filling up of the inter-particle voids. The cation exchange decreases the surface area and thickness of the clay layer and promotes flocculation which implies that the water-soil-SAM mixture can be compacted with lower water content.

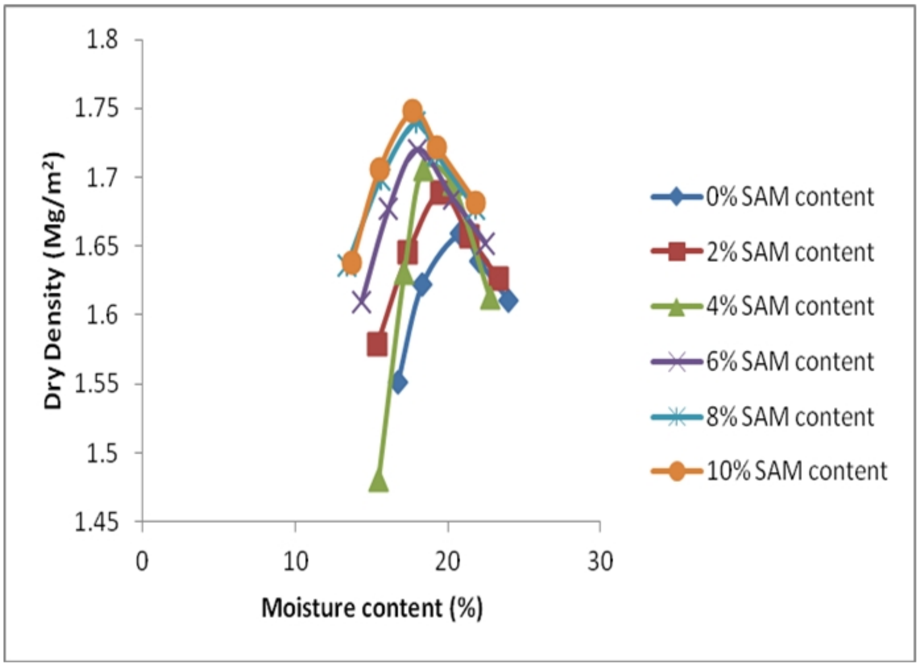

Fig. 3. Moisture-Dry density relationship with varying SAM content for the soil mixture

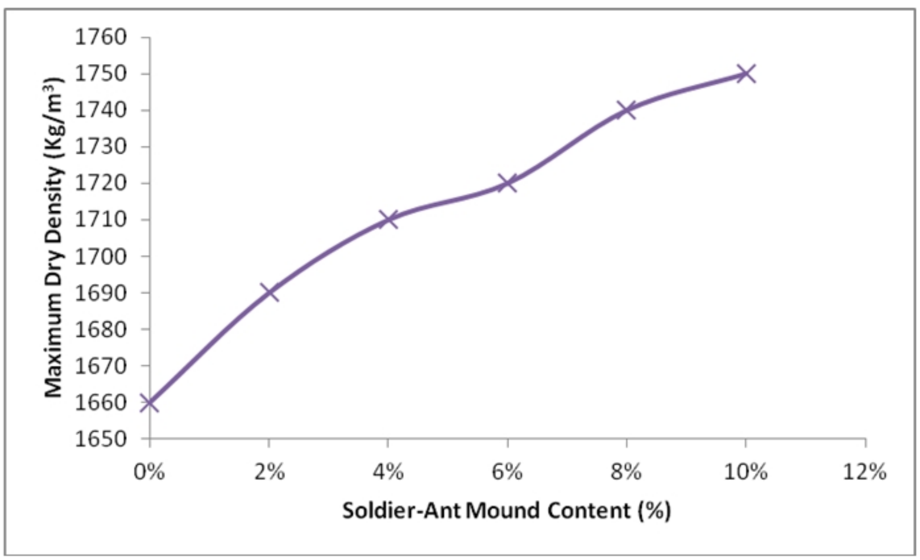

Fig. 4. Variation of Maximum dry density with SAM content for the soil mixture

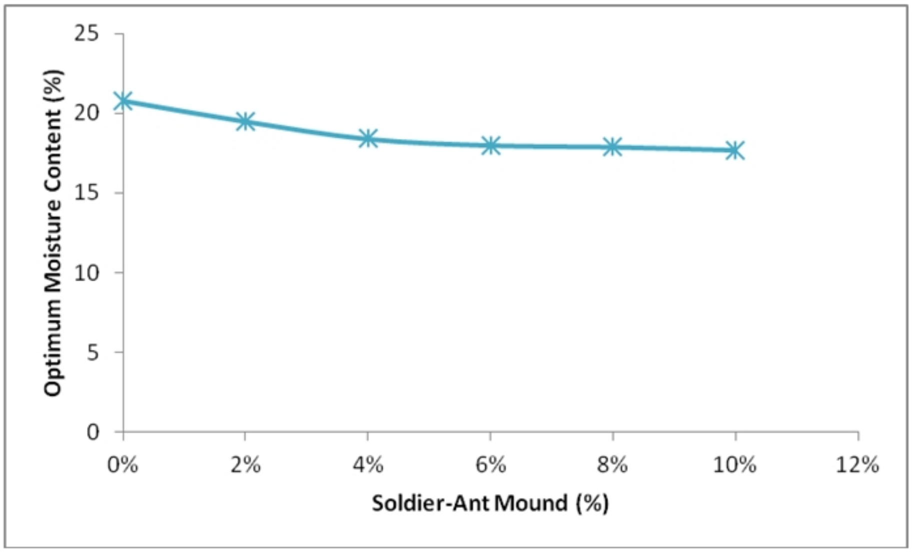

Fig. 5. Variation of Optimum moisture content with varying SAM content for the soil mixture

3.5 Effect on the Strength Characteristics

3.5.1 Effect on california bearing ratio

The CBR test was carried out using the results of the West Africa Standard (WAS) compaction test. The results of the CBR test and swelling potential measured during the test are presented below Figs. 6 and 7. The results indicate that there is appreciable increase in strength with the addition of Soldier-Ant Mound to the lateritic clay soil while the swelling potential reduced. The soaked CBR of the natural soil increased with increase in Soldier-Ant Mound content Fig. 6. The swelling potential decreased with increase in SAM content Fig. 7. The soaked CBR increased by about 85% from 10.43% to 19.35% at 10% soldier-ant mound content. The swelling potential decreased by about 11% from 0.0812 to 0.0722 at 10% SAM content. The reduction in swelling potential confirms the strength gain and is a positive indication of potential reduction in road deformation due to swelling. Although the soaked CBR at 10% fell below the minimum CBR requirement of 40% for sub-base, but based on the results, there is evidence that the Soaked CBR increases with increase in the SAM content and the addition of SAM content above 10% may give the required CBR of above 40%.

The increase in soaked CBR can be attributed to the formation of new compounds as a result of the cation exchange and filling up of the inter-particle voids in the soil-SAM matrix. The bonds between the compounds are strong preventing the entrance of water molecules to breakdown during soaking.

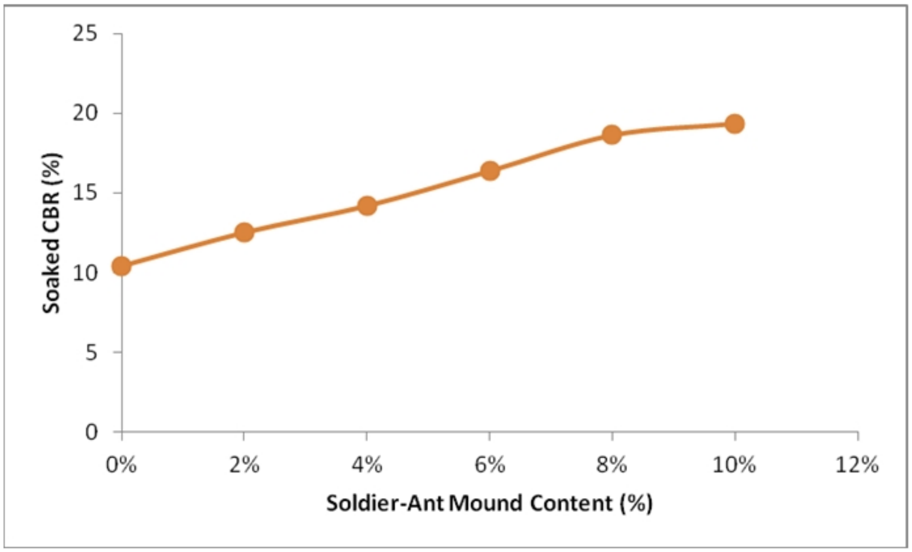

Fig. 6. Variation of Soaked CBR with SAM content for the soil samples

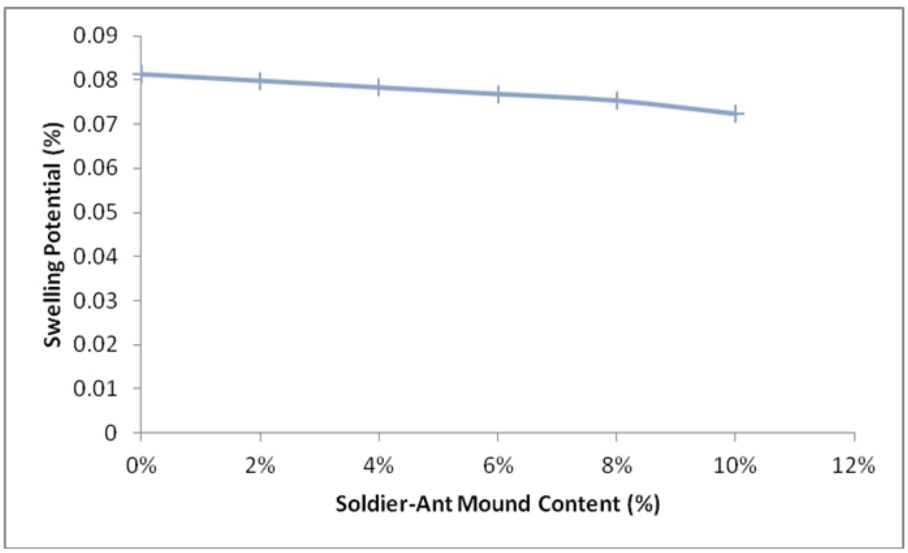

Fig. 7. Variation of swelling potential with SAM content for the soil samples

3.5.2 Effect on the unconfined compressive strength

The Unconfined compressive strength of the lateritic clay soil increased with the addition of Soldier-Ant Mound Fig. 8. The Unconfined compressive strength increased from 40.32KN/m^2 for the natural clay soil to 89.36KN/m^2 at 10% SAM content. This is about 122% increase. The increase may be due to proper matching of matrix interface and filler interface which promotes strength. Composite strength and toughness are strongly affected by particle/matrix adhesion as strength depends on effective stress transfer between filler and matrix while toughness/brittleness is controlled by adhesion [26]. The better the mixing, the better the dispersion and diffusion and consequently the stabilization process [27].

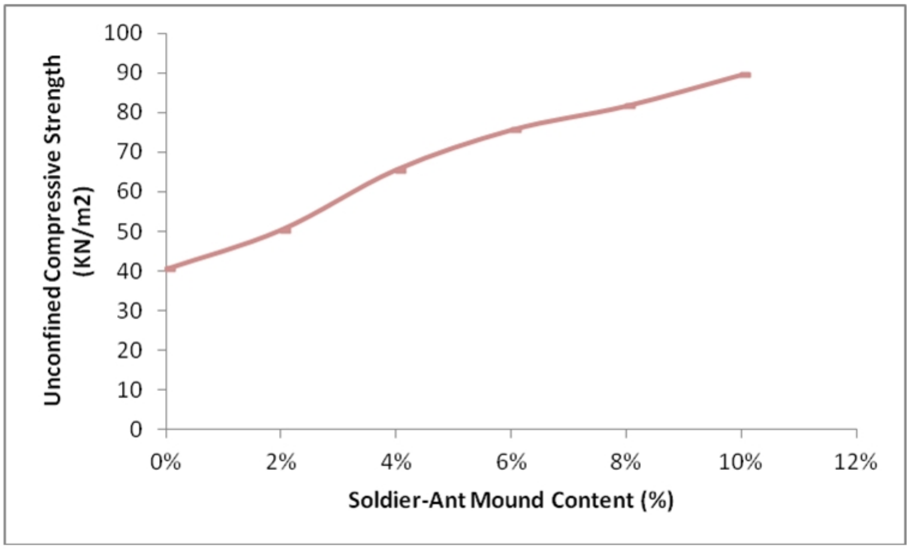

Fig. 8. Variation of unconfined compressive strength with SAM content

4. CONCLUSION

The results of the experiments carried out to investigate the effects of Soldier-Ant Mound on the strength characteristics of Lateritic Clay Soil show that:

I. Generally, the addition of SAM improved the strength characteristics of the Lateritic Clay Soil.
II. The Plasticity Index decreased with increase in Soldier-Ant Mound (SAM). The addition of 10% SAM content decreased the plasticity index by about 7.5% (from 25.8% for the natural soil to 23.9%). The reduction signifies a reduction in any swelling and deformation that may take place.
III. The addition of SAM improved the compaction characteristics of lateritic clay soils. The maximum dry density increased with increase in SAM content while the optimum moisture content decreased. The addition of 10% SAM content increased the maximum dry density, MDD, of the clay soil from 1660kg/m^3 to 1750kg/m^3 which is considered satisfactory to excellent while the optimum moisture content, OMC, decreased by about 15%. The trend is opposite to that of the effect of lime on clay soils.
IV. The addition of SAM increased the soaked CBR and unconfined compressive strength of the Lateritic Clay Soil. The addition of 10% SAM content increased the soaked CBR by 85% (from 10.43% to 19.35%) while the unconfined compressive strength of the Lateritic Clay Soil increased by 122% (from 40.32kN/m^2 to 89.36kN/m^2).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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