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Original Research Article

Effects of Partial Replacement of Cement and Lime with some Agrowaste Ashes on the Geotechnical Behaviour of Lateritic Soil

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Abstract

In this study, the optimum stabilizer content for a poor lateritic soil intended as subgrade material for a pavement was sought. The natural soil was first characterized and classified and the soil fall into the class of A-6 based on Nigeria General Specifications for Roads and Bridges (NGSRB) AASHTO soil class for pavement construction. The soil was stabilized at three binder points of 4%, 8% and 12% which coincided with specification limits for cement based on NGSRB with the range of 7-11% recommended for soils in the class A-6. The results from the compaction tests and unconfined compressive strength (UCS) tests show that the suitable stabilizer falls within the specified range of 7 – 11%. Binder contents/proportions of 4% RHA, 8% RHA, 8% (50R + 50O), 4% (60C/L + 40R/O), 8% (70C/L + 30R/O), 8% (0C/L + 100R/O), 8% (50C/L + 50R/O) gave the most promising results of MDUW and UCS. In other to carry out a comprehensive investigation of the properties of the soil to determine which of the promising binder contents/proportions would be most suitable as stabilizer for the soil, it was recommended that other qualifying tests of specific gravity, Atterberg limits, CBR, UCS, durability and permeability tests be carried out for these recommended binder contents/proportions.

Keywords: Cement, Compaction, Clay, Laterite, Lime, Oil palm empty fruit bunch ash, Rice husk ash.

1.0 INTRODUCTION

The effort to cut down greenhouse emissions has cut across many sectors of the world economy and development. The construction industry and petrochemical industry comes top among the greatest contributors to greenhouse gas emissions. Buildings is believed to consume 30 – 40% of the world's energy consumption, generates 30 – 40% wastes and 30 – 40% of greenhouse gases released annually (UNEP, Umar and Khamidi, 2012; Mezie *et al.*, 2022). The greenhouse gas emissions in buildings would largely be linked to the usage of cement in the construction of buildings which is still very common in most countries of the world.

In road construction works, there is always the increasing need to stabilize the soil due to increasing wheel loads on our soils or the substantial presence of clay silicate minerals on the soil that affects its strength and stability under load (Osinubi and Mustapha, 2008). These stabilization works have hitherto been done with calcium-based stabilisers which is predominantly cement and lime (Anggraini *et al.*, 2016; Bahmani *et al.*, 2016; Abdeldjouad *et al.*, 2019). These substances over the years have proven to be reliable stabilizers by improving many of the engineering properties of the soil. However, they have adverse effect on the environment and they also have high impact on the cost of road construction (Oriola and Moses, 2010; Abdu *et al.*, 2017). Cement for instance is believed to produce as much as 7% of the world's carbon dioxide emission due to its carbonate composition (Matthews *et al.*, 2009; Abdeldjouad *et al.*, 2019). As the impact of greenhouse gases becomes more glaring on the world and the need for stabilised roads continues to increase due to increasing human population, economic activities and developmental efforts, these substances no longer has potent contributions to a sustainable world. Hence, there is the need to develop an alternative stabilizer or auxiliary stabilizer to cement and lime.

Waste products, mostly bio-based and agro-based wastes have increasingly been researched into as a cheap, environmentally friendly alternative to cement and lime. There are large tons of agricultural wastes in the world to the tune of more than one (1) billion per year (Obi *et al.*, 2016) and the incineration of such wastes cause problem to the environment (Nguyen *et al.*, 2019). In the past, rice husk ash (Oyetola *et al.*, 2006) banana leaves ash (Kanning *et al.*, 2014), periwinkle shell ash (Nnochiri and Aderinlewo, 2016; Dauda *et al.,* 2018), corn cob ash (Apampa and Jimoh, 2014; Nnochiri and Adetayo, 2019), groundnut shell ash (Otoko *et al.*, 2014), bagasse ash (Osinubi *et al.*, 2009; Ghandi, 2012), snail shell ash (Nnochiri *et al.*, 2018), palm bunch ash (Onyelowe, 2017), yam peel ash (Ramonu *et al.*, 2019) have been used independently to stabilize soils. This was made possible by the pozzolanic properties of these ashes (Attah *et al.*, 2021). Some of the ashes have also been previously used in conjunction with cement (Apampa and Jimoh, 2014; Akinwumi and Aidomojie 2015, Onyelowe and Onuoha, 2016, Coutinho and Papadakis, 2011) and lime (Hasan *et al.*, 2016) in soil stabilisation. There have been few researches found where the ashes were binary blended to stabilize soils as auxiliary additive to cement or lime or as replacement materials. Attah *et al.*, (2021) binary blended an industrial waste, cement kiln dust (CKD) with rice husk ash (RHA) and they discovered improvement in the maximum dry density of the soil (MDD), the California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) of the stabilised soil. While the usage of CKD may have solved the problem of disposal of such wastes, which is the key aim of the research, the material cannot be divulged from contributing to some level of greenhouse gases. Owing to the increasing availability of these agro waste products due to the growing population, there is the increasing need to enhance the concept of waste to wealth through the re-use of the waste products. The research focuses on blending the agro wastes to partially replace cement and lime, in an effort to reduce the quantity of cement and lime in use without compromising strength and stability.

2.0 TEST MATERIALS AND METHODS

2.1 Test Materials

The base material used for this study was a lateritic soil obtained from a borrow pit in Anambra state, Nigeria by method of disturbed soil sampling at a depth between 1 – 2 m. The soil after collection was kept in an airtight bag and returned to the geotechnical laboratory of Nnamdi Azikiwe University, Awka. Other materials are stabilisers that include, cement, lime, oil palm empty fruit bunch ash (OPEFBA) and rice husk ash (RHA). The cement used for the work belongs to the BUA cement brand which was bought from cement vendor shop in Awka. Hydrated lime (Ca $(OH)_2$ was bought from the market in Onitsha, Anambra State. RHA was produced from rice husk obtained from a rice mill at Anaku in Anyamelum Local Government Area of Anambra state. The rice husk was calcined to white ash at temperature of 700^{o}C at Scientific Equipment Development Institute (SEDI), Enugu. The oil palm empty fruit bunch was gotten from palm oil producers at Igbariam in Anambra East Local Government Area of Anambra state. The palm bunch was also calcined at temperature of 700^{o}C also at SEDI to produce the OPEFBA. The OPEFBA and RHA after production were kept airtight in polythene container to avoid interference with air because of their hygroscopic nature. Figures 1 (a and b) shows the OPEFBA and RHA after having been burnt to white ash. To get the suitable size of ashes before use, they were ground at ball-milling machine and then sieved through 75µm sieve to increase their surface area and hence enhance reactivity with the soil (Abdeldjouad *et al.*, 2019, Attah *et al.*, 2021).

a b

Figure 1: (a) Oil palm empty fruit bunch ash (OPEFBA) after burning to white ash; (b) Rice husk ash (RHA) after burning to white ash

2.2 Testing Methods

The methods adopted in the work are laboratory tests to investigate the important engineering properties expected from unstabilized and stabilized soils. The properties tested which include: specific gravity, Atterberg limits and sieve analysis for the classification of the natural soil and then compaction test and unconfined compressive strength (UCS) tests for the natural soil and the stabilized soils were carried out according to BS 1377 specifications. Prior to each of the tests, the lateritic soil used for the test was first air-dried in the laboratory, cleared of all debris and then pulverized to disaggregate lumped soils.

2.3 Mixing Methods

The mixing methods describing the binder contents/proportions are outlined in Table 1. Three binder points were investigated for the constituents. The binder points which are 4%, 8% and 12% were chosen based on what is obtainable in existing literature and also to coincide with the lower limit and upper limit of cement binder contents/proportions according to Nigeria General Specifications for Roads and Bridges-NGSRB (1997). The maximum binder point of 12% was chosen based on the clause 6229 of NGSRB (1997) which recommended that soils within the class A-5 to A-7 of American Association of State Highway and Transportation Officials (AASHTO) soil classification system and which requires as much as 12% cement for stabilisation are no longer economical and should preferably be replaced.

Table 1: Description of Soil Binder Contents/Proportions

Cement (C)	Lime (L)	RHA/OPEFBA	C/L-R/O
0% of Soil (S)	0% S	4% S-100R/0O	4% S- (100C/L + 0O/R)
2% S	2% S	4% S-50R/50O	4% S-(90C/L + 10O/R)
4% S	4% S	4% S-0R/100O	4%-80/20
6% S	6% S	8% S-100R/0O	4%-70/30
8% S	8% S	8% S-50R/50O	4%-60/40
10% S	10% S	8% S-0R/100O	4%-50/50
12% S	12% S	12% S-100R/0O	4%-0/100
		12% S-50R/50O	8%-100/0
		12% S-0R/100O	8%-90/10
			8%-80/20
			8%-70/30
			8%-60/40
			8%-50/50
			8%-0/100
			12%-100/0
			12%-90/10
			12%-80/20
			12%-70/30
			12%-60/40
			12%-50/50
			12%-0/100

From Table 1, C stands for cement, L stands for lime, S stands for soil, R stands for rice husk ash (RHA) while O stands for oil palm empty fruit bunch ash (OPEFBA). In the first column, two binders were used; RHA (R) and OPEFBA (O). 4%S – (100R/0O) means that 4% of dry weight of soil was the binder content added to the soil. However in this 4%, 100R implies that only RHA constitute the 4%. 4%S – (50R/50O) means that 4% of dry weight of soil was the binder content added to the soil. However, in this 4%, 50R implies that half of the 4% (2%) is RHA while the other half is OPEFBA. The same rule applies to others. In the second column, four binders were used; C, L, R and O. 4%S – (100C/L + 0R/O) means that 4% of dry weight of soil was the binder content added to the soil. In the 4%, 100C/L implies that the whole of the binder content is C and L. The ratio of this C to L is always 1:1. 4%S – (90C/L + 10R/O) means that 4% of dry weight of soil was the binder content added to the soil. In the 4%, 90C/L implies that 90 parts of the 4% constitute C and L at ratio 1:1 while 10 parts of the 4% constitute R and O at ratio 1:1. The same rule applies to other mixtures.

3.0 RESULTS AND DISCUSSION

3.1 Material Characterization

The natural soil was first characterized where the properties that include specific gravity, Atterberg limits, particle size analysis (Figure 2), and compaction properties were determined for the natural soil with the intention to classify the soil and use it is as benchmark to compare to the compaction characteristics of the stabilized soil. Table 2 shows the physical properties of the natural soil that was used to classify the soil. The natural soil was classified as A-6 based on AASHTO soil classification system. Based on NGSRB (1997), the soil is not suitable as subgrade material in road construction and would need improvement of its properties. The cement content required to improve the soil would come within the range 7 – 11%. The laterite, OPEFBA and RHA possess specific gravities of 2.59, 2.24 and 1.96 respectively. The Maximum dry unit weight (MDUW) has a value of 17.76 kN/m^3 while the optimum moisture content (OMC) has a value of 14.9%. The plasticity index of the soil is 15.2% which are within the range of medium plasticity and the unsoaked CBR value of 7% further confirms that the soil is unsuitable as subgrade material for road construction purposes and therefore needs improvement.

Table 2: Physical properties of natural lateritic soil

Basic soil property	Value
Specific Gravity (Laterite)	2.59
Specific Gravity (OPEFBA)	2.24
Specific Gravity (RHA)	1.96
Liquid Limit (%)	38
Plasticity Index (%)	15.2
MDUW (Kn/m^3)	17.76
OMC (%)	14.9
Fines Content (%)	41.304
AASHTO Soil Class	A-6
CBR (unsoaked) (%)	7
Colour	Reddish-brown

3.2 Particle Size Analysis

The grading curve of the soil as shown in Figure 2 shows that the soil is at the interfaces of well-graded to gap-graded soil. Since the soil does not have D_{10} and D_{30} from the grading curve, it was not possible to determine the grading of the soil based on the values of coefficient of curvature (C_c) and coefficient of uniformity (C_u). However, the fines content of the soil is 41.304% which is higher than 35% benchmark of AASHTO for soils where the fines content influences the behaviour of the soil.

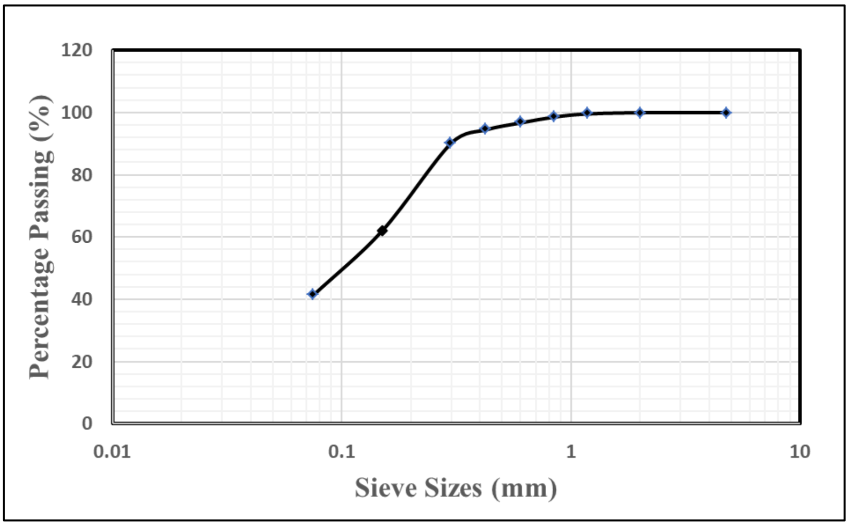

Figure 2: Grading curve of natural soil

3.3 Oxide Composition of Natural Soil/Properties of Stabilisers that affect Soil

The oxide composition of the lateritic soil was examined using X-ray Fluorescence (XRF) test as shown in Table 3. The lateritic soil has a silica (SiO_2) content of 57.9596%, aluminum oxide (Al_2O_3) content of 26.6295% and ferric oxide (Fe_2O_3) content of 12.703%. When defining soil based on the ratios of silica (SiO_2) to sesquioxides (Fe_2O_3 + Al_2O_3), the soil has a value of 1.47 which shows that the soil is lateritic soil (Ola, 1976).

Cement and lime are conventional stabilisers and are generally characterized by high percentage of calcium oxide (CaO) which is natural for cementitious materials. Previous researches carried out by Sarapu (2016), Oviya and Manikandan (2016) and Ayodele *et al.,* (2021) has continued to show that RHA come in the class of pozzolans with the sum of quantities of SiO_2, Al_2O_3 and Fe_2O_3 exceeding 70% (ASTM C618, 2005). According to Ndife (2021), Basha *et al.,* (2005) opined that RHA cannot be used alone in soil stabilization but have to be used in conjunction with cement/lime because of its lack of cementitious properties. OPEFBA does not fully satisfy the requirements of pozzolan but often contains appreciable quantities of SiO_2 and potassium oxide (K_2O) (Omar *et al.*, 2011).

Table 3: Oxide Composition of Natural Lateritic Soil

Oxides	Composition (%)
Al_2O_3	26.6295
SiO_2	57.9596
K_2O	0.9671
Fe_2O_3	12.7063
MnO	0.0025
ZrO_2	0.0308
Nb_2O_5	0.0192
MoO_3	0.0030
Ag_2O	0.0048
CdO	0.0145
PbO	0.0029
LOI	11.38

3.4 Effect of the Binders on the Compaction Characteristics (MDUW/OMC) of the Stabilized Soil

The binder contents described in Table 1 were used to stabilize the soil and the compaction behaviours were studied. The results are presented in Figures 3 to 8. There was decrease in the MDUW with the addition of binder contents across most of the binder contents especially those at the 12% binder content. This is because the higher amounts of binders especially OPEFB and RHA with lower specific gravities lead to an increase in volume and decrease in the dry densities of the soil. This aligns with the work of Ayodele *et al.*, (2021). This shows that the optimum stabilizer for the soil lies between 4% and 10% and thereby conforms to the range specified by NGSRB (1997). 4% RHA and 8% RHA produced the most promising stabilisers among the non-conventional stabilisers. With the reduction of cement content, most of the stabilisers gave MDUW values greater than the 17.266 kN/m^3 which is the minimum MDUW expected for soil to be used as subgrade material based on the recommendation by the NGSRB (1997).

Similarly, the OMC recorded higher values for soils stabilized with binder contents of 12%. This was attributed to an increased desire for water due to the higher contents of binders because more water is required to dissociate of admixture with Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction or the increasing surface area of the additives that require more water for the lubrication of the mixture (Etim *et al.*, 2020).

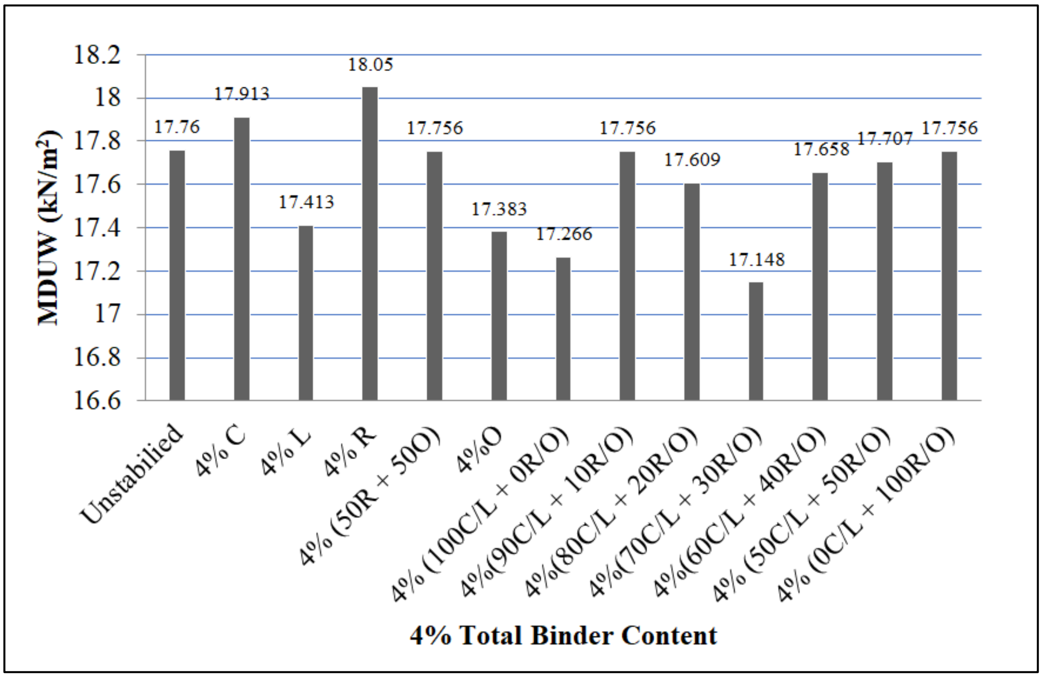

Figure 3: MDUW of soil stabilized at 4% total binder content

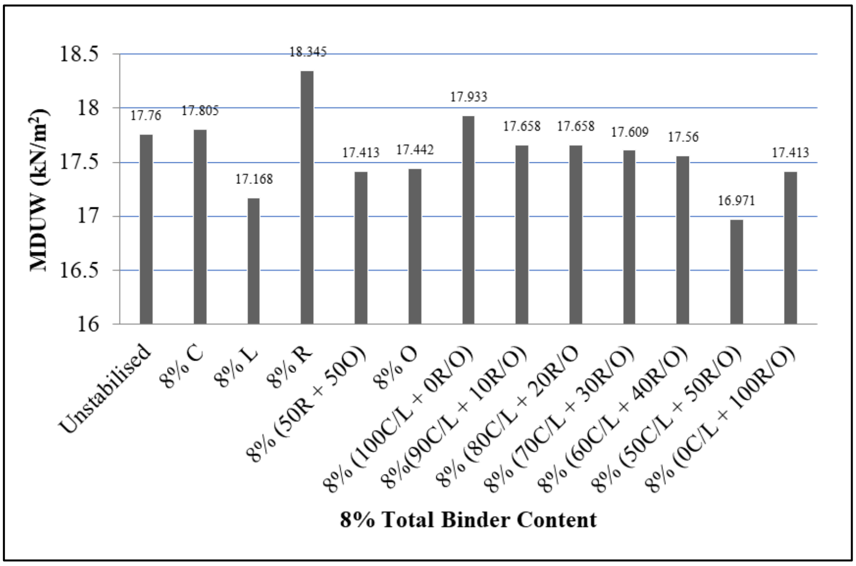

Figure 4: MDUW of soil stabilized at 8% total binder content

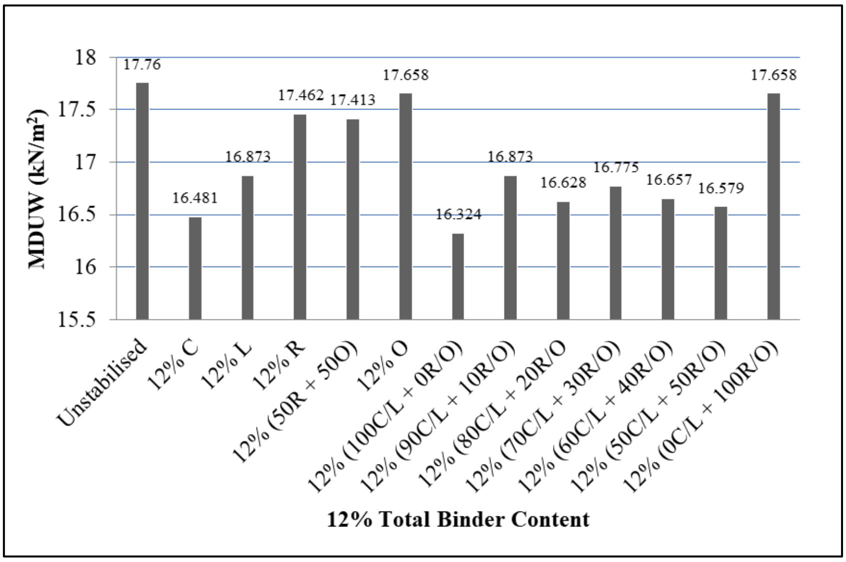

Figure 5: MDUW of soil stabilized at 12% total binder content

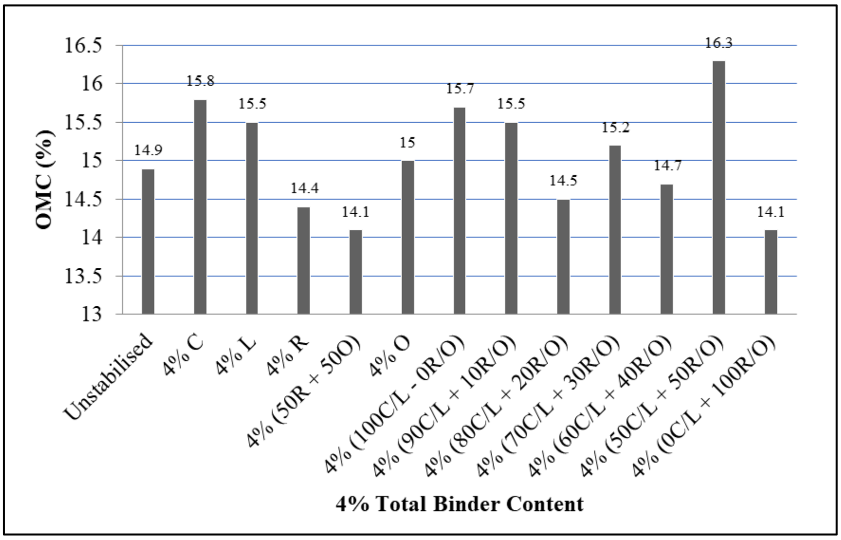

Figure 6: OMC of soil stabilized at 4% total binder content

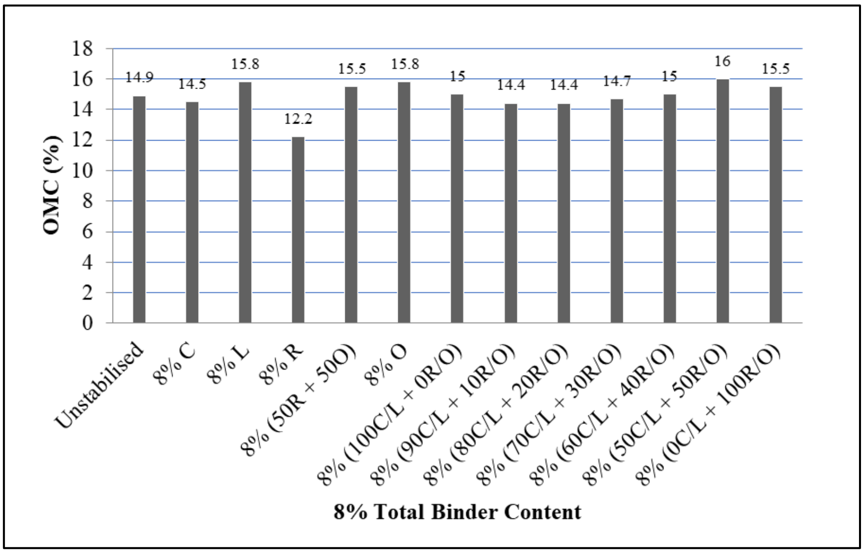

Figure 7: OMC of soil stabilized at 8% total binder content

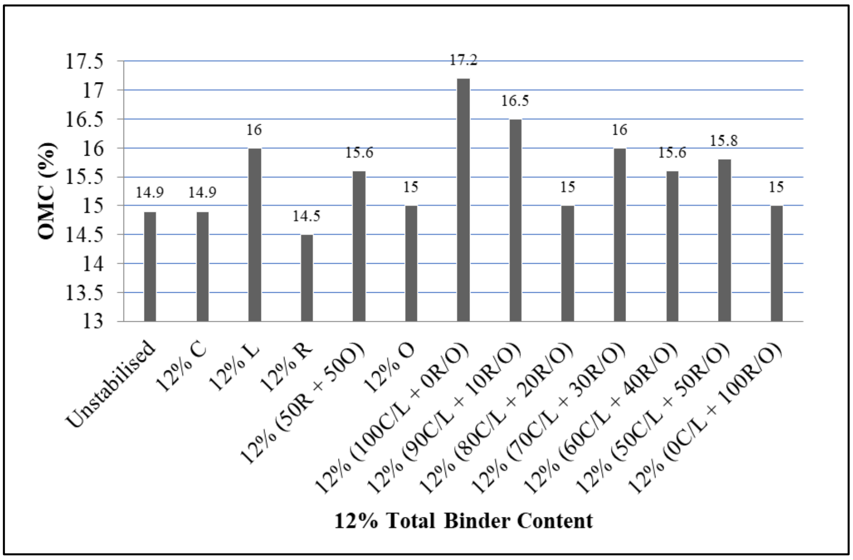

Figure 8: OMC of soil stabilized at 12% total binder content

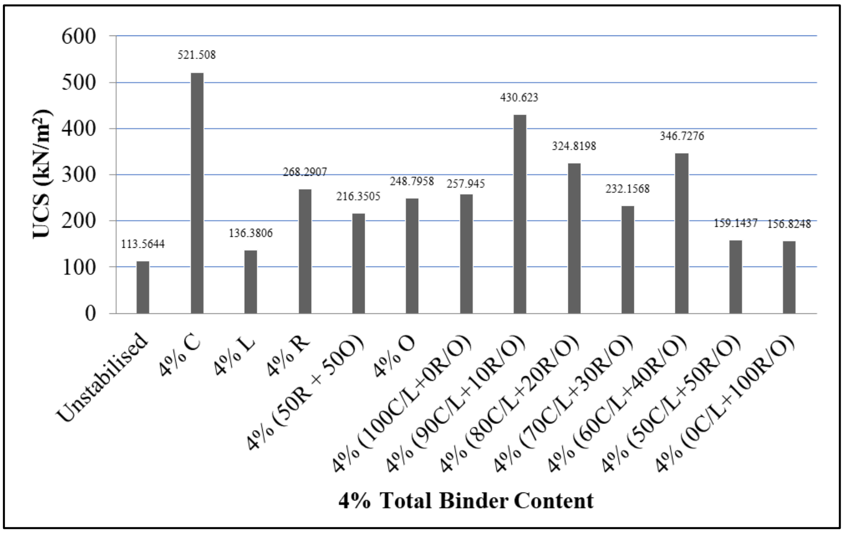

Figure 9: UCS of soil stabilized at 4% total binder content

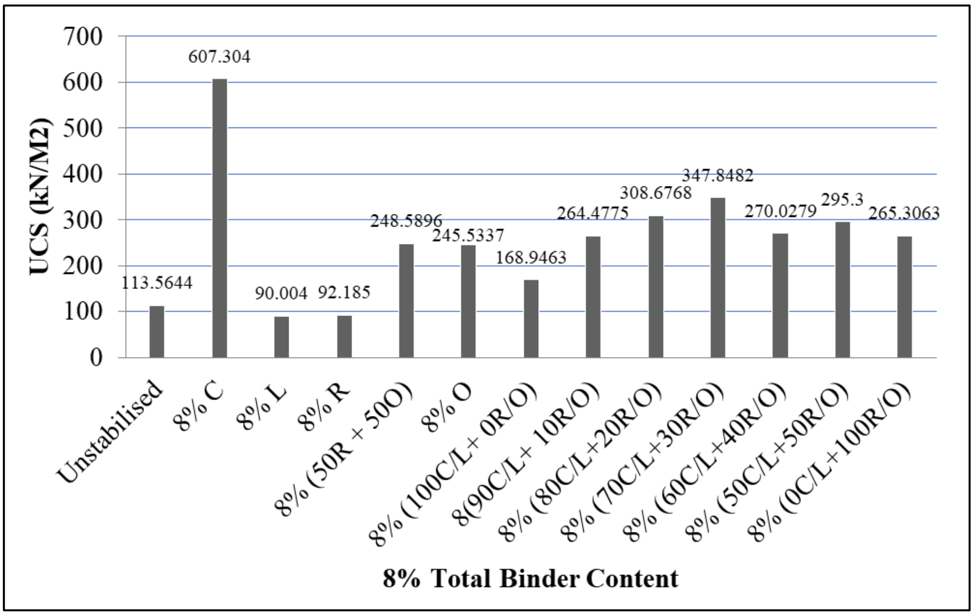

Figure 10: UCS of soil stabilized at 8% total binder content

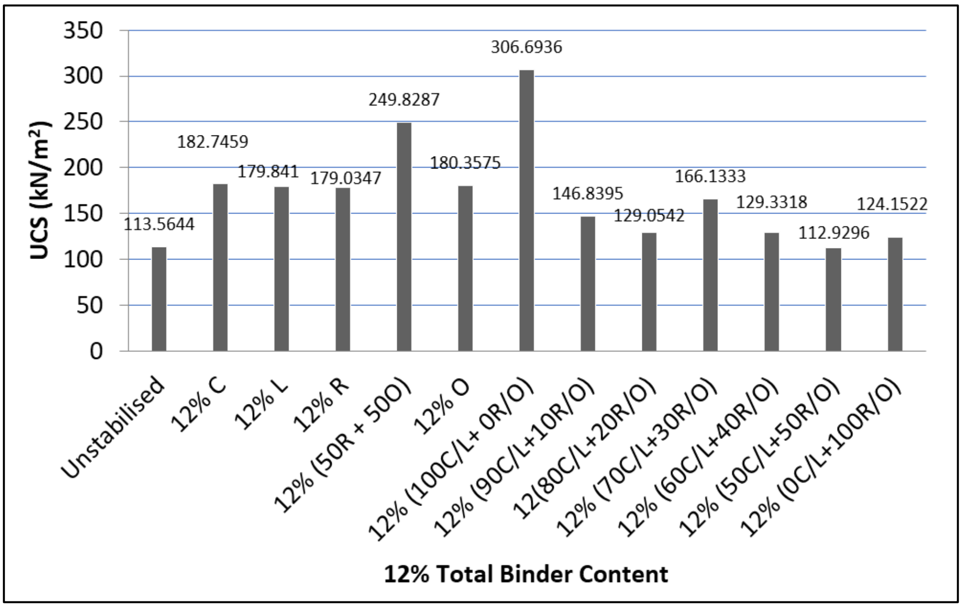

Figure 11: UCS of soil stabilized at 12% total binder content

3.5 Effect of the binders on the unconfined compressive strength of the stabilized soil

Unconfined compressive strength (UCS) is one of the engineering properties of that can be used to access the suitable amount of additives required to stabilize the soil. Figure 9 - 11 shows the effect of the binder contents on the UCS of the stabilized soils. There was general improvement in the UCS of the stabilized soils when compared to the ustabilized soil. The best performing soil was at 4% (90C/L + 10R/O). However, using this binder content would defeat our purpose for this test which is to reduce the quantity of conventional stabilisers of cement and lime. 4% (60C/L + 40R/O), 8% (70C/L + 30R/O) and 8% (50C/L + 50R/O) gave the most promising results where the agrowaste ashes partially replace cement and lime.

3.6 Comparisons of Results across Equi-binders

The chats below shows the performance of the observed UCS and MDUW values across the binder contents. Three binder points of 4%, 8% and 12% were plotted in one chart accordingly.

A. Maximum Dry Unit Weight (MDUW)

Figure 12 shows the effect of variation of binders on the MDUW of the soil at the three binder points for the different combination of binders.

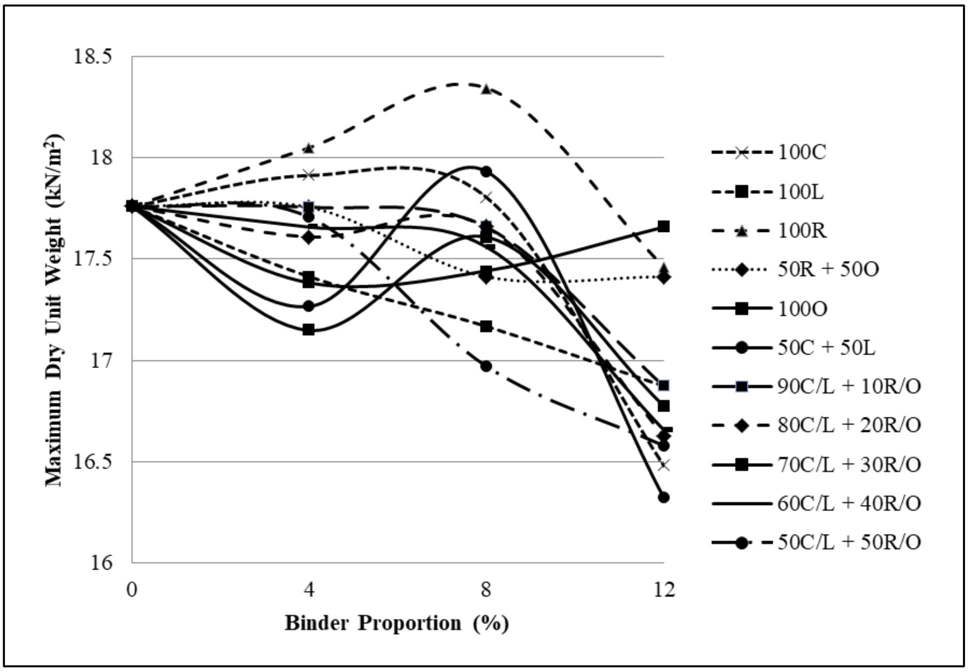

Figure 12: Effect of variation of binder contents on the MDUW of the lateritic soil

From Figure 12, it can be seen the some of the constituents did not influence the MDUW of the soil significantly. 100C at 4%, 100R at 8% and 50C + 50L at 8% have the most remarkable influence on the MDUW of the soil. Beyond 8% binder for most of the constituents, the MDUW of the soil decreased at 12% except for 100O. This shows that the optimum stabilizer for the soil lies between 4% and 10%. 100R gave a very promising outcome. However, the performance under moist condition is yet to be ascertained. Hence its strength cannot be certified. In the partial replacement of cement with agrowaste ashes, 90C/L + 10R/O and 80C/L + 20R/O gave the most promising outcome. At these percentages, the cement/lime content is still high and not recommended.

B. Optimum Moisture Content (OMC)

Figure 13 shows the effect of variation of binders on the OMC of the soil at the three binder points for the different combination of binders.

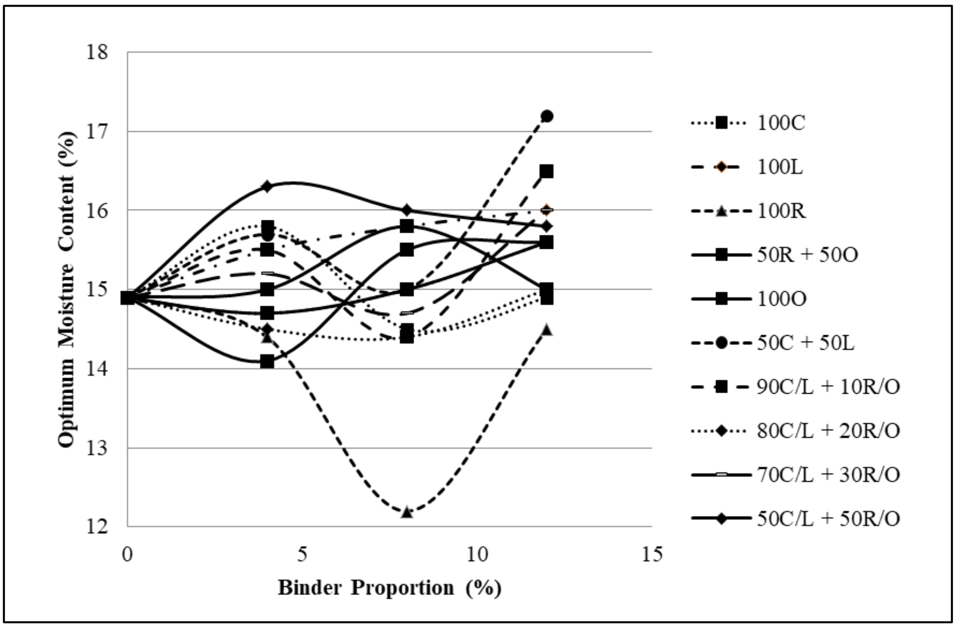

Figure 13: Effect of variation of binder contents on the OMC of the lateritic soil

From Figure 13, there was not any particular trend observed for the moisture content, though, it is expected that since the binder content is by addition and not by replacement, the OMC required to achieve an MDD should increase proportionally. The trend seems to align for most of the soils especially at the 12%

binder content. Comparison between compaction curves obtained at different compaction energies usually show clear disparity between the OMC values. However, since one compaction energy is being used for this test, the variation OMC with binder contents may not be a significant indicator of the behavior of the stabilized soil.

C. Unconfined Compressive Strength (UCS)

Figure 14 shows the effect of variation of binders on the UCS of the soil at the three binder points for the different combination of binders.

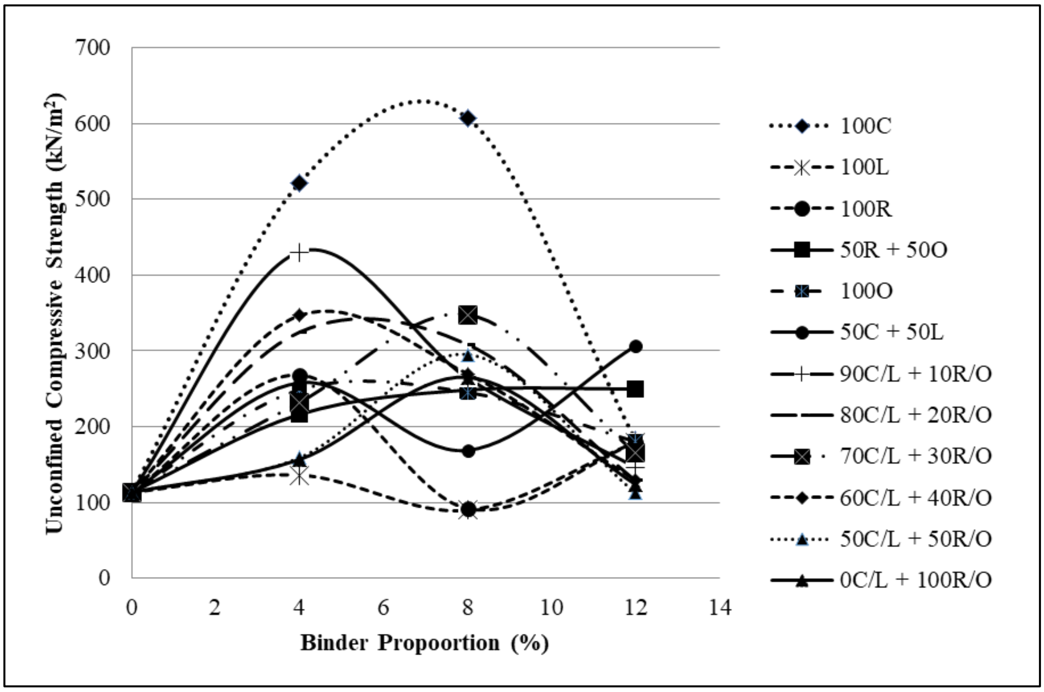

Figure 14: Effect of variation of binder contents on the UCS of the lateritic soil

From Figure 14, it can be seen that 100% cement content influenced the UCS of the stabilized soil most especially within the range of 4% to 8% of total binder content. Though 100% cement content gave the maximum UCS value, it is not sustainable and does not satisfy our objective for the research. Other binder contents that gave promising values with lesser amount of cement such as 4% RHA, 4% (60C/L + 40R/O), 8% (70C/L + 30R/O) etc gave promising values for consideration.

3.7 SUMMARY OF FINDINGS

Considering our initial objective to obtained zero – cement/lime or less-cement/lime based stabilizers. The most promising binder contents are summarized in Table 4. 8% RHA gave the highest value of MDUW of 18.3 kN/m^2, a little difference from its value at 4% RHA while the UCS value decreased from 265 kN/m^2 at 4% RHA to 90 kN/m^2 at 8% RHA. The high amount of dry materials in the mix at 8% RHA may have contributed to this because of the low specific gravity of RHA. However, it is anticipated that if the mix is subjected to curing, there could be improvement in the UCS at 8% RHA. Generally, at 4% of the mix, there seems to be noticeable better performance of the mix in terms of MDUW with the performance of the UCS at 8% of the mix showing promising values despite having higher amount of dry materials. It is anticipated that if the mix at 8% is properly cured, it could give better values in strength than the mix at 4%.

Table 4: MDUW and UCS values of seven best performing binder contents

Best Performing Binder Contents	MDUW (kN/m^3)	UCS (kN/m^2)
4% RHA	18.05	265
8% RHA	18.3	90
8% (50R + 50O)	17.4	250
4% (60C/L + 40R/O)	17.65	340
8% (70C/L + 30R/O)	17.55	340
8% (0C/L + 100R/O)	17.4	265
8% (50C/L + 50R/O)	16.98	290

4.0 CONCLUSION AND RECOMMENDATION

The compaction behaviour of lateritic soil stabilized with a blend of RHA and OPEFBA as partial replacement for blend of cement and lime was studied in this work. The aim was to produce stabilisers that are not entirely cement/lime bound and which should also be durable enough as stabilizer for subgrade of road pavement. Three optimum binder contents (OBC) of 4%, 8% and 12% were used to coincide with the recommended limit of cement used for stabilisation of various soils in the AASHTO class according NGSRB (1997). Results obtained from the test shows that binder contents beyond 8% is not suitable for the road. This is because the binders around 12% gave low values for both MDUW and UCS. When the soil was stabilized with only cement and lime, there was significant improvement in the MDUW and UCS of the soils. However, this would still generate enormous greenhouse gases when used at such rates. When the soil was stabilized with only agrowastes and with blend of cement/lime and RHA/OPEFBA, the following combinations: 4% RHA, 8% RHA, 8% (50R + 50O), 4% (60C/L + 40R/O), 8% (70C/L + 30R/O), 8% (0C/L + 100R/O), 8% (50C/L + 50R/O) gave the most promising results of MDUW and UCS which fall appreciably within the specification limits in NGSRB (1997). It is recommended that these binder contents be subjected to further tests of specific gravity, Atterberg limits, CBR, UCS, durability and permeability tests to ascertain which of them would gave the most promising results and be most suitable to stabilize the soil.

CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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