ASSESSMENT OF THE EFFECT OF SOME SELECTED ADDITIVES ON THE STABILIZATION OF AN EXPANSIVE SOIL FOR ROAD CONSTRUCTION

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ABSTRACT

Expansive soils are those that experience significant volume change as moisture content changes, which render the soil unsuitable for road a construction, necessitating soil stabilization. This study created a framework for combining waste-derived chemical additives in the most effective way possible for expansive soil stabilization. Lime, rice husk ash and saw dust ash were mixed with the soil at varying percentages and combined using varied compositions during the study. The results showed that lime outperformed the other additives when applied alone with a CBR of 18.82% and a PI of 2.52% at 10% Lime. For the dual additives combinations, Lime-Rice husk ash performed better while for the three additives combinations, 6% lime with 12.5% RHA and 8% SDA gave the best result of 29.88% CBR and 3.83% PI. This study found that the waste materials analyzed can be used to alter the qualities of expansive soil for long-term road construction.

KEY WORDS: Expansive Clay Soil, Lime, Rice husk ash, Saw Dust ash, Chemical Stabilization, Additives, Road Construction.

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1. INTRODUCTION

Various types of soils are employed in civil engineering projects; however, some soil deposits in their natural condition are adequate for construction purposes, and others, such as problematic soils, are unsuitable without treatment. These soils must be dug and refilled, or their qualities must be adjusted, before they can withstand the loads produced by the top structures. Expansive soils are typical of problematic soils and can be found all across the world except in the Arctic areas (Steinburg, 2000). Expansive soil is a form of clayey soil that contains the mineral montmorillonite, which expands when exposed to water and contracts after the water evaporates. This type of soil is mostly found in dry and semi-arid climates. The swelling of expansive soil caused by absorbed water causes significant harm to structures built on this type of soil. As a result of uneven soil movement, these structures frequently suffer serious damage from settlements or heave resulting in increased maintenance costs. (Petry & Little, 2002). There are a variety of unique approaches for building on this type of terrain. One of them is the use of stabilizers to change the physical and chemical properties of the soil. For expansive soils like clay, engineers prefer physicochemical modification of the soil to achieve durability compared to outright excavation and replacement of soil due to cost implications. (Buhler, 2007; Hussey et al., 2010).

2. LITERATURE REVIEW

Any physical, chemical, biological or combination method of modifying a natural soil to fulfil an engineering objective is referred to as soil stabilization. The mechanical and chemical stabilization methods are commonly used for soil stabilizations. (Estabragh et al., 2013a; Estabragh et al., 2014; Radhakrishnan et al., 2017; Soltani et al., 2018b). Chemical stabilization entails adding chemicals to the soil such as lime, cement, asphalt, or a combination of these. When additives are introduced into a soil, they react with the natural soil ingredients, resulting in increased strength, changes in porosity, volume, density, permeability, waterproofing and reduced surface abrasion as well as the cementation of soil particles. Chemical stabilization often leads to savings in construction costs of civil-engineering applications such as road construction, earth-wall construction, foundation, and other earthworks purposes. Chemical Stabilization techniques can be classified into two groups based on the application of traditional or non-traditional agents. Each of the two methods may be used independently or simultaneously, in an attempt to optimize each benefit. (Petry & Little, 2002).

Traditional agents are chemical additives that have been around for a long time and are used to stabilize expansive soils. These agents are often calcium-based and consist of lime, cement and fly-ash. As a result, when exposed to water, they undergo both instant and prolonged time-dependent chemical reactions with the soil or other additives, resulting in an overall improvement of the soil matrix in terms of swell reduction, shear strength improvement and resistance to the influence of drying and wetting (Soltani, 2017a). Cation exchange, flocculation and agglomeration, pozzolanic reaction, and carbonate cementation have been identified as the mechanisms of stabilization for traditional agents (Firozzi et al., 2017; Al-Swaidani et al., 2016). However, issues such as heaving-induced sulphate attack caused by soil-lime sulphate reactions, the effect of organic material that inhibit the reaction of calcium-based additives, the environmental impacts of the cement manufacturing process and carbonation reactions call into question the long-term viability of using traditional stabilizers. (Jayanthi & Singh, 2016; Firozzi et al., 2017). Non-traditional agents are additives that chemically react with the soil and/or other additives, frequently in the presence of enough moisture to engender physiochemical reactions in the soil matrix. Industrial by-product materials (such as cement kiln dust, lime kiln dust, ground granulated granulated blast furnace slag, pulverized coal bottom ash, steel slag, mine tailings, and others), other waste products with calcium oxide content (such as waste paper sludge ash), sulphonated oils, ionic compounds, and polymers are examples of these materials. (Petry & Little, 2002; Alazigha et al., 2016; Fasihnikoutalab et al., 2017; Estabragh et al., 2018)

Nigeria is Africa's fifth-largest producer and second-largest producer of wood/timber after China. Rice husk and saw dust are by-products of the rice and wood processing industries, and they are produced in massive numbers every day. Rice husk and saw dust output is estimated to be over 200 million tonnes per year (Soosan et al., 2005), with disposal posing numerous geo-environmental issues. Rice husk ash is a byproduct of the rice husk burning process that has a high percentage of amorphous silica and is used in a variety of applications. Recent studies also proved the beneficial effect of rice husk ash a super pozzolanic material with lime or cement in improving soil properties. Utilization of solid wastes in this manner not only protects the environment from degradation but also improves the engineering properties of the expansive soil. This study is thus based on the evaluation of the geotechnical characteristics of expansive clay subjected on the effect of mixture of chemical additives extracted from ashes of solid wastes

3. METHODOLOGY

3.1 Materials

3.1.1 Black cotton soil

The expansive soil that would be stabilized is the black cotton soil in Numan, Adamawa State, Nigeria. Numan is located at latitude 9°29'10"N and longitude 12°02'36"E of the Nigerian geographical map. The collection of the sample would be performed through disturbed sampling method using the hand carved sampling method. It would be collected at a depth of between 0.4 to about 1.0m. The sample would then be placed in an air-tight bags and taken to the geotechnical laboratory where it is going to be pulverized using an hammer

3.1.2 Lime

Lime is one of the chemical additives that will be used for this study. The lime is calcium oxide (CaO) also known as quick lime or burnt lime. It is white, caustic, alkaline and crystalline at solid temperature (Ikeagwuani *et al.,* 2016). It is relatively inexpensive and it is manufactured by heating limestone, coral, sea shells or chalk, which are mainly $CaCO_3$, to drive off carbon dioxide. It has a melting point of 2600°C.

3.1.3 RICE HUSK ASH

Rice husk is profusely available in rice producing countries like India, China, Indonesia, Thailand and more recently Nigeria. Rice husk is mainly used as a fuel in industries in Boilers for process energy requirements and for power generations. Rice husk ash is an industrial waste generated during firing process of paddy husk, containing a good percentage of amorphous silica and is being used in many applications. Rice husk was obtained from local rice mill and burnt in a tube in basket rice husk burner. The ash so obtained was powdered and sieved through 600μ IS sieve. Ash fraction that passed through 600μ IS sieve would be used for study.

3.1.4 SAW DUST ASH

Saw dust was obtained from a saw mill at a timber shed in Akure. It would be collected with the help of a shovel from the heap of saw dust produced immediately and clean without traces of bark of trees in large quantities. The collected saw dust would then be placed in the furnace and burnt at a temperature of about 800°C until all the sawdust is turned to ash. After the burning of the Sawdust into ash, it would be allowed to cool gently in the Furnace. This is done to prevent the ingress of moisture before being removed. The resulting Sawdust ash produced would then be sieved through 75um British test sieve and placed in air-tight polythene Bags until it is ready for use.

3.2 Experimental Procedure

All experimental procedure was carried out using the British Standard for the testing of soil. Index properties tests were carried out on the black cotton soil to determine the soil inherent physical properties in order to classify the soil using the AASHTO classification system. This index properties include percentage by weight of fines, gravel and sand in the soil, specific gravity, Plastic and Liquid limit, Maximum dry density and optimum moisture content, colour and differential free swell test. The chemical properties of the stabilizers which include lime, rice husk ash and saw dust ash were determined using X-ray fluorescent Analysis.

3.3 The Stabilized Soil Experimental Set-up

Tests were performed on samples of black cotton soil. Lime, rice husk ash and saw dust ash mixture (BC-LRHASDA) with lime (L) varied at a percentage of 0, 2,4,6,8,10,12; rice husk ash (RHA) varied at a percentage of 0,5,7.5,10,12.5; with sawdust ash (SDA) varied at a percentage of 0,4,8,12,16. All varied by weight of the black cotton soil. The tests include: Atterberg limits (Liquid limit, Plastic limit, Plasticity index), Compaction (Maximum dry density and optimum moisture content), California Bearing ratio (% CBR at 0, 7 and 28 days). A total of 175 stabilized soil samples were prepared and experimental tests performed on them. The experimental information database gathered were then used in developing the ANN model for CBR prediction at 0, 7 and 28 days of curing.

4. RESULTS AND DISCUSSION

4.1 Materials Chemical Composition

Table 1 showed the result of the chemical analysis and XRD tests performed on the black cotton soil, lime, rice husk ash and the saw dust ash

4.2 Effect of each singular additives on the expansive clay soil behavior

4.2.1 LIME

4.2.1.1 ATTERBERG LIMIT

Fig. 1 shows the effect of Lime on the Atterberg limits (Liquid limit, Plastic limit, Plasticity Index) of the black cotton expansive clay soil. The result showed a continuous gradual decrease in the optimum moisture content up to 4% lime addition, followed by a sharp increase at 6% lime content. Another decrease was experienced at 8% lime addition. At lime addition above 8%, an upward/increase in the optimum moisture content was experienced, with the highest increased experienced at 12% lime content. This result put the optimal lime addition for optimum moisture of the expansive clay soil sample at 12%.

4.2.1.2 CALIFORNIA BEARING RATIO RESULT

The California Bearing ratio which is a measure of load resisting ability of the soil is an important properties in the use of a particular soil as subgrade material in road construction. Figure 2 showed the effect of Lime on the California bearing ratio of the expansive clay soil. The result showed a gradual increase in the California bearing ratio of the expansive clay soil with the addition of lime content, and the increase is continuous up to the soaked CBR samples up to 28 days. However, the increase is up to 10% lime content, after which a decline in the CBR was experienced at lime content above 10%. This result put the optimal lime stabilizer addition for improvement of expansive clay soil for road construction at 10%.

4.2.2 RICE-HUSK ASH

4.2.2.1 ATTERBERG LIMIT

Figure 3 showed the effect of Rice husk ash (RHA) on the Atterberg limit (Liquid limit, Plastic limit, Plasticity Index) of the expansive clay soil. The result showed a decrease in the liquid limit of the expansive clay soil with the addition of the rice husk ash. The maximum decrease occurred at 7.5% rice husk ash condition. Plastic limit of the expansive clay soil also experienced a decrease with the blending of RHA with the maximum reduction occurring at 7.5% rice husk ash content. The same result applied to the plasticity index of the expansive clay soil with the minimum occurring at 7.5% RHA addition.

4.2.2.2 California Bearing Ratio result

Figure 4 showed the effect of Rice husk ash (RHA) on the California bearing ratio of the expansive clay soil. The result showed a gradual increase in the California bearing ratio of the expansive clay soil with the addition of RHA content, and the increase is continuous up to the soaked CBR samples up to 21 days. However, the increase is up to 7.5% RHA content, after which a decline in the CBR was experienced at RHA content between 7.5% to 10%, after which there was an increase at 12.5% which was not up to the increase experienced at 7.5% This result put the optimal RHA stabilizer addition for improvement of expansive clay soil for road construction at 7.5%.

4.2.3 SAW DUST ASH

4.2.3.1 Atterberg Limit

Figure 5 showed the effect of Saw dust ash (SDA) on the Atterberg limit(Liquid limit, Plastic limit, Plasticity Index) of the expansive clay soil**.** The result showed a decrease in the liquid limit of the expansive clay soil with the addition of the saw dust ash. The maximum decrease occurred at 16% saw dust ash condition. Plastic limit of the expansive clay soil also experienced a decrease with the blending of RHA with the maximum reduction occurring at 8% saw dust ash content. Above the 8% SDA addition, an increase in the plastic limit was experienced up to 16% SDA addition. The plasticity index of the expansive clay soil decreased with the addition of the saw dust ash with the minimum occurring at 16% SDA addition.

4.2.3.2 CALIFORNIA BEARING RATIO

Figure 6 showed the effect of Saw dust ash (SDA) on the California bearing ratio of the expansive clay soil. The result showed a gradual increase in the California bearing ratio of the expansive clay soil with the addition of SDA content, and the increase is continuous up to 16% SDA for the soaked CBR samples up to 21 days. This result put the optimal SDA stabilizer addition for improvement of expansive clay soil for road construction at 16%.

4.2.4 COMPACTION PROPERTIES

4.2.4.1 MAXIMUM DRY DENSITY

Figure 7 showed the effect of each additives used singly on the dry density of the expansive clay soil. The result showed a decrease in the maximum dry density of the expansive clay soil sample with additions of the additives. The maximum reduction occurred at 7.5% RHA addition with dry density of 1.18, after which the density started increasing. This was followed by Lime at 10% with dry density of 1.20 while that of Saw dush ash was 1.22 at 16% addition.

4.2.4.2 OPTIMUM MOISTURE CONTENT

Figure 8 showed the effect of Rice husk ash (RHA) on the moisture content of the expansive clay soil. The result showed an increase in the optimum moisture content of the expansive clay soil with the addition of the additives. The maximum increase occurred at 7.5% RHA addition with optimum moisture content of 39.40, after which the moisture content started decreasing. This was followed by Lime at 12% with optimum moisture content of 38.85 while that of Saw dush ash was 38.65 at 16% addition.

*4.2.5 **Performance Comparison of each singular additives towards the stabilization of the expansive clay***

Table 2 showed the most optimal percentage of each stabilizer that will yield the maximum effect on the expansive clay soil. The main criterion for the choice of the optimal stabilizer percentage content is one that yields the highest CBR value. Other criteria include the lowest dry density, the lowest plasticity index and the highest optimum moisture content.

Where:

LL	is	Liquid limit
PL	is	Plastic limit
PI	is	Plasticity Index
MDD	is	Maximum Dry Density
OMC	is	Optimum Moisture Content
CBR	is	California Bearing ratio

From the table, Lime at 10% showed higher CBR compared to the other additives. It also showed the lowest Plasticity Index compared to the other additives. Rice husk ash showed the lowest MDD while Saw dust ash showed the highest OMC. Since lime outperformed the other additives in two variables, it showed that Lime is the better stabilizer when used alone in stabilizing the expansive clay soil.

These same graphical analyses that was done to evaluate the effect of each single additives on the expansive clay soil was performed on effect of each dual additives (i.e RHA-SDA, Lime-RHA, Lime-SDA) combinations and all possible combinations of the three additives together i.e RHA-SDA combinations with 2%,4%,6%,8%,10% and 12% lime content. The most optimal combinations of all the additives considered were picked and compared with one another to check the best performing additives combinations in enhancing the performance of the expansive clay soil.

4.2 Performance characteristics of each dual additives combinations toward the stabilization of the expansive clay

Table 3 showed the most optimal percentage of each dual stabilizer combinations that is the most effective in the stabilization of the expansive clay soil. The main criteria for the choice of the optimal stabilizer percentage content is one that yields the highest CBR value. Other criteria include the lowest dry density, the lowest plasticity index and the highest optimum moisture content.

Where:

LL	is	Liquid limit
PL	is	Plastic limit
PI	is	Plasticity Index
MDD	is	Maximum Dry Density
OMC	is	Optimum Moisture Content
CBR	is	California Bearing ratio
RHA	is	Rice husk ash
SDA	is	Saw dust ash

From the table containing values for the optimal additives percentages, Lime at 10% with rice husk ash at 12.5% showed higher CBR at both 7 and 14days compared to the other additives combination. It also showed the lowest Plasticity Index compared to the other additives combination. The lime-Saw dust combination showed the lowest MDD and highest OMC. Since the Lime-RHA combination outperformed the other additives in all CBR values and also the PI, it showed that Lime-RHA combination is the better stabilizer when used together in stabilizing the expansive clay soil.

4.3 Performance characteristics of the three additives combinations toward the stabilization of the expansive clay

Table 4 showed the most optimal percentage of RHA-SDA combinations with 2-12% Lime addition, that was the most effective in the stabilization of the expansive clay soil. The main criteria for the choice of the optimal stabilizer percentage content is one that yields the highest CBR value. Other criteria include the lowest dry density, the lowest plasticity index and the highest optimum moisture content.

Where:

LL	is	Liquid limit
PL	is	Plastic limit
PI	is	Plasticity Index
MDD	is	Maximum Dry Density
OMC	is	Optimum Moisture Content
CBR	is	California Bearing ratio
RHA	is	Rice husk ash
SDA	is	Saw dust ash

From the table containing values for the optimal additives percentages, Lime at 6% with rice husk ash at 12.5% and saw dust ash with 8% showed higher CBR at 21days compared to the other additives combination. It also showed the lowest Plasticity Index compared to the other additives combination. It also showed the lowest MDD and the maximum OMC compared to the other additives combination. Since the 6%Lime-12.5%RHA-8%SDA combination outperformed the other additives, it showed its effectiveness as the best stabilizer combinations when all additives are used together in stabilizing the expansive clay soil.

5. CONCLUSION

- The optimal lime additives addition for improvement of expansive clay soil for road construction is at 10%Lime content
- The optimal Rice Husk Ash additives addition for improvement of expansive clay soil for road construction is at 7.5%RHA content
- The optimal Saw Dust Ash stabilizer addition for improvement of expansive clay soil for road construction is at 16%SDA content
- Comparing the performance of the three additives used singly in stabilizing expansive soil, Lime outperformed the other additives and is the better stabilizer when used alone in stabilizing the expansive clay soil.
- 6%Lime & 12.5% RHA is the most effective lime-rice husk ash combination in the stabilization of the expansive clay soil
- 8%Lime & 16%SDA is the most effective lime-saw dust ash combination in the stabilization of the expansive clay soil
- 10% RHA & 16%SDA is the most effective rice husk ash-saw dust ash combination in the stabilization of the expansive clay soil.
- Comparing the performance of the three additives combined dually in stabilizing expansive soil, Lime-Rice husk ash combination outperformed the other additives and is the better dual additives combination stabilizer on the expansive clay soil.
- Comparing the performance of the RHA-SDA combinations with 2%-12% lime content, which contain all combinations of the three additives together, the 8%Lime & 12.5% RHA with 16%SDA outperformed the other additives and is the better additives combination stabilizer on the expansive clay soil.

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Table 1: Chemical elements of research materials

Chemical elements	Clay (%)	Rice Husk Ash(RHA)	Hydrated Lime (%)	Saw Dust ash (%)
Silica(SiO_2)	51.39	89.08	0.00	62.87
Alumina(Al_2O_3)	17.21	1.75	0.13	9.87
Iron(Fe_2O_3)	9.33	0.78	0.08	4.45
Calcium(CaO)	3.66	1.29	59.03	10.35
Magnesium oxide (MgO)	1.17	0.64	0.25	4.21
Sodium(Na_2O)	1.72	0.85	0.05	0.035
Potassium(K_2O)	0.39	1.38	0.03	1.71
Manganese oxide (MnO)	0.25	0.14	0.004	0.00
Titanium(TiO_2)	0.98	0.00	0.00	0.00
P_2O_5	0.17	0.61	0.00	0.00
H_20	4.23	1.33	0.04	0.00
Loss on Ignition(LOI)	9.48	2.05	40.33	5.85

Table 2: Optimum Percentages of Each Stabilizer Additives

		Atterberg Limits			**Compaction**		**CBR**		
Additives	**Percentages (%)**	**LL**	**PL**	**PI**	**MDD**	**OMC**	**% @ 0 days**	**% @ 7days**	**%@ 14days**
Lime	10	49.16	46.64	2.52	1.20	34.83	12.00	14.89	18.82
Rice husk ash	7.5	64.53	31.22	33.17	1.18	39.4	6.39	8.16	11.35
Saw dust ash	16	61.11	35.18	25.93	1.22	38.65	5.47	7.99	11

Table 3: Optimum Percentages of Each Dual Stabilizer Additives Combinations

		Atterberg Limits			Compaction		CBR		
Additives	**Percentages (%)**	**LL**	**PL**	**PI**	**MDD**	**OMC**	**% @ 0 days**	**% @ 7days**	**%@ 14days**
Lime-RHA	6%Lime & 12.5% RHA	62.91	57.18	5.73	1.15	32.50	16.30	18.38	19.24
Lime-SDA	8%Lime & 16%SDA	59.43	42.24	17.19	1.13	39.23	13.44	14.76	16.88
RHA-SDA	10% RHA & 16%SDA	56.55	44.28	12.27	1.14	38.56	8.17	10.12	13.10

Table 4: Optimum Percentages of the three Stabilizer Additives Combinations

		Atterberg Limits			Compaction		CBR		
Additives	**Percentages (%)**	**LL**	**PL**	**PI**	**MDD**	**OMC**	**% @ 0 days**	**% @ 7days**	**%@ 14days**
Lime-RHA-SDA	2%Lime & 12.5% RHA with 16%SDA	56.88	50.11	6.77	1.10	42.00	15.77	18.98	22.33
	4%Lime & 12.5% RHA with 16%SDA	49.11	45.00	4.11	1.08	43.33	20.00	22.18	27.00
	6%Lime & 12.5% RHA & 8%SDA	55.22	51.39	3.83	1.05	44.54	20.59	24.89	29.88
	8%Lime & 12.5% RHA with 16%SDA	57.78	46.90	10.88	1.08	38.90	16.10	18.77	19.98
	10%Lime & 12.5% RHA with 16%SDA	58.90	47.60	11.30	1.10	42.00	19.90	22.00	25.10
	12%Lime & 12.5% RHA with 16%SDA	59.87	49.99	9.88	1.08	42.88	22.89	24.87	27.89

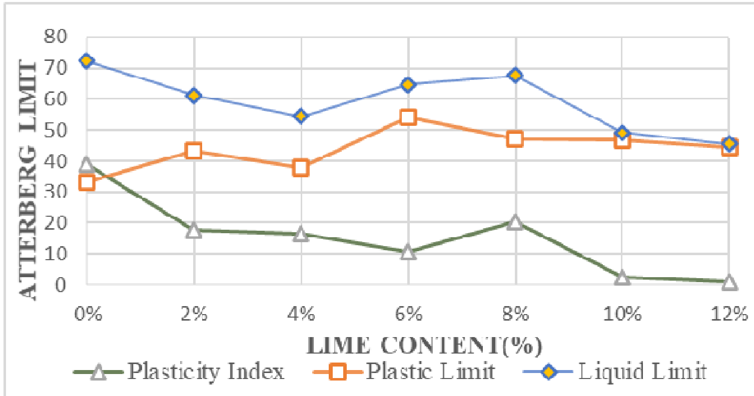

Figure 1: Effect of Lime on the Atterberg Limits of Black cotton soil.

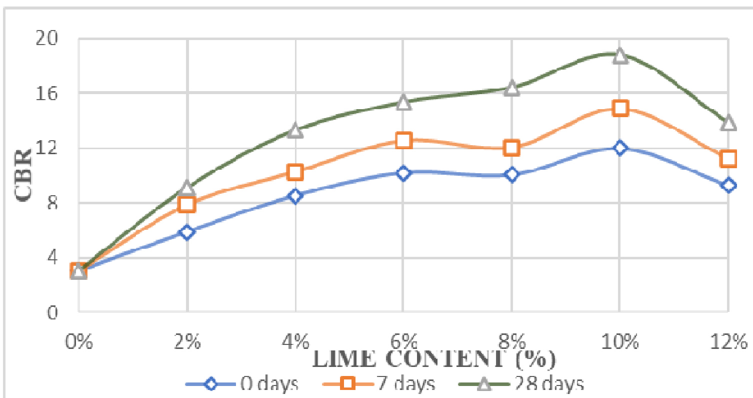

Figure 2: Effect of Lime on the California Bearing Ratio

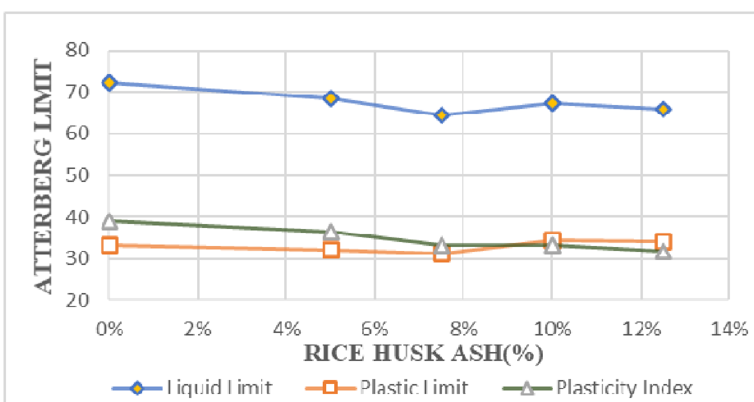

Figure 3: Effect of Rice husk ash on the Atterberg Properties of Black cotton soil.

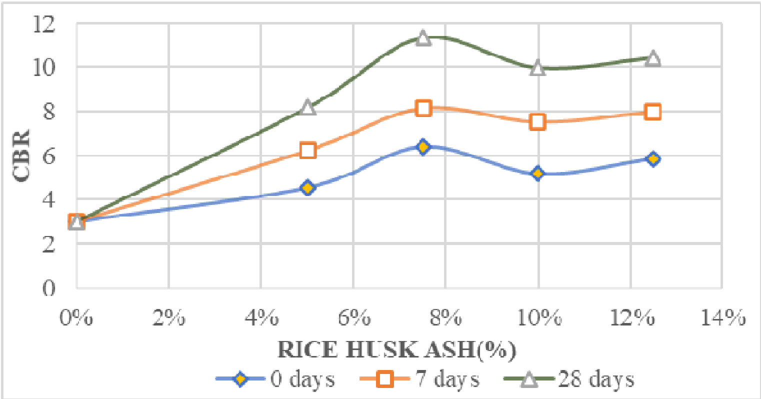

Figure 4: Effect of Rice husk ash on the California Bearing Ratio

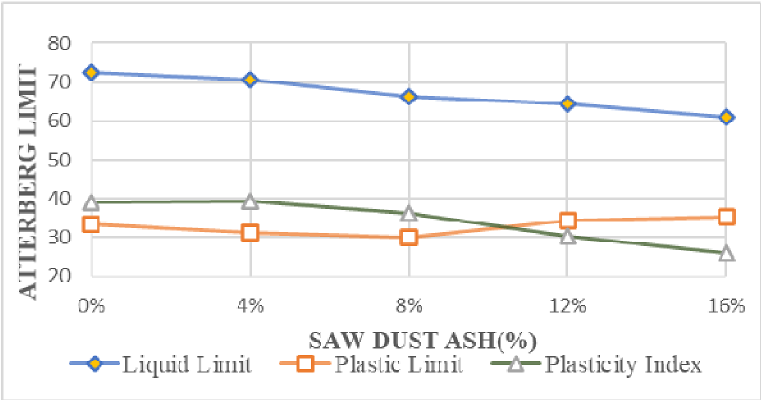

Figure 5: Effect of Saw dust ash on the Atterberg Limits

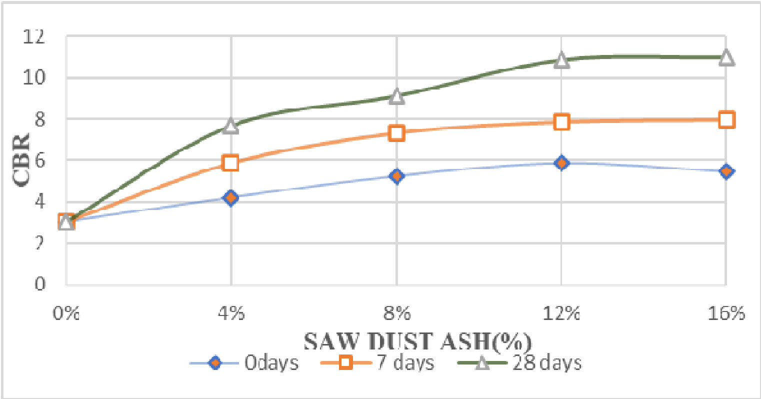

Figure 6: Effect of Saw Dust Ash on the California Bearing Ratio Properties

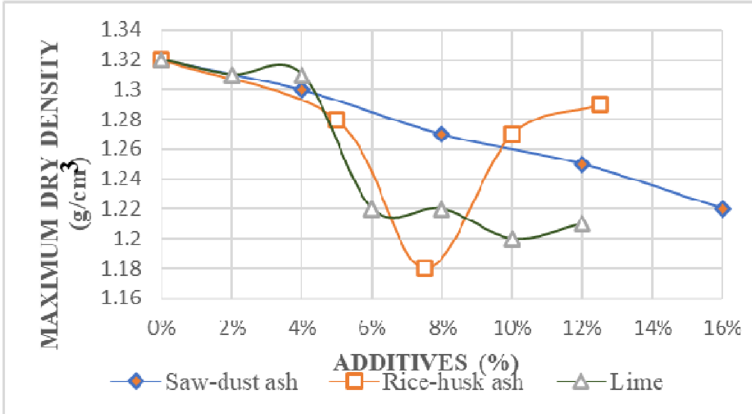

Figure 7: Effect of Additives used alone on Maximum Dry Density

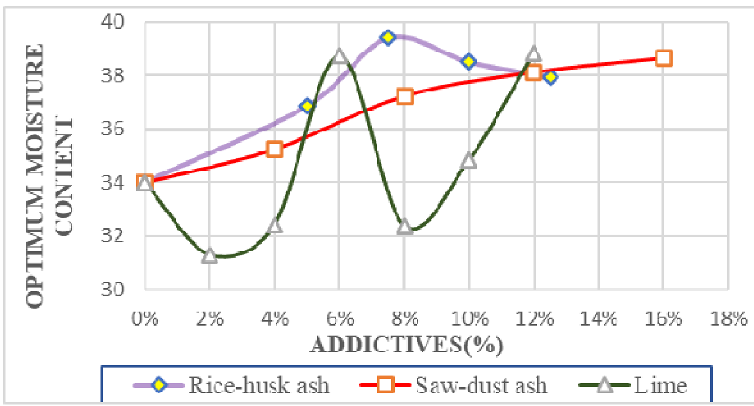

Figure 8: Effect of RHA on the Optimum Moisture Content) Properties