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Research Article

Stabilization of Road subbase using Spear Grass ash

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Abstract

This study investigates the potential of spear grass ash (SGA) as a stabilizing agent for road subbase materials, focusing on its effect on the physical and mechanical properties of the material. Key laboratory tests were conducted to evaluate the impact of varying SGA contents (2-10%) on particle size distribution, Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR) values, both soaked and unsoaked. The sieve analysis results demonstrated that the soil used for the subbase was moderately well-graded, with low plasticity as indicated by a plasticity index of 8.1%. Compaction tests revealed an optimal dry density of 1.96 g/cm³ and optimum moisture content of 15% at 4% SGA content. CBR test results further highlighted the effectiveness of SGA in enhancing load-bearing capacity, with peak unsoaked and soaked CBR values of 86.5% and 37.7%, respectively, also observed at 4% SGA. These findings suggest that SGA is an effective stabilizing agent, with an optimal application range of 4-6% for enhancing subbase strength and stability. Based on these results, it is concluded that SGA can serve as an eco-friendly alternative to traditional stabilizers for road construction. Recommendations include further field testing and long-term durability studies to validate SGA's performance under dynamic loads and environmental fluctuations, as well as exploring optimization in the SGA preparation process to ensure consistency. This research contributes to sustainable road construction practices by presenting SGA as a viable, low-cost, and environmentally conscious stabilizing agent for subbase materials.

Keyword: Stabilization, Spear grass ash (SGA), Subbase, Compaction, CBR, Atterberg Limits

INTRODUCTION

The construction and maintenance of road infrastructure are critical components of modern society, facilitating the movement of goods, services, and people, and supporting economic development (Ibrahim and Hassan, 2020). However, the integrity and longevity of roads can be compromised by various factors, with subbase instability emerging as a significant concern. The subbase layer of roads, situated beneath the pavement structure, serves as a foundation that distributes loads and provides structural support (Terzaghi and Peck, 1967). When the subbase lacks adequate stability, it can lead to a range of issues, including pavement deformation, rutting, cracking, and ultimately, premature road failure (Bini and Lippmann, 2020).

Traditionally, road subbases have been constructed using natural aggregates such as crushed stone, gravel, or sand. While these materials offer satisfactory performance under certain conditions, they may not always provide the required strength and stability, particularly in regions with weak or expansive soils, high traffic volumes, or challenging environmental conditions (Ramu, 2019). In such cases, additional measures are needed to enhance the resilience and durability of road subbases, ensuring the long-term sustainability of transportation infrastructure (Muntohar and Hantoro, 2010).

In recent years, there has been growing interest in exploring alternative materials and techniques for road construction and stabilization, driven by concerns over resource depletion, environmental degradation, and the need for more sustainable infrastructure solutions (Okafor and Onukwube, 2004). Agricultural waste materials, including various types of biomass ash, have emerged as viable candidates for enhancing the mechanical properties of soils and aggregates used in road subbase construction. These materials offer several advantages, including abundance, low cost, and potential environmental benefits, such as reducing the demand for natural resources and mitigating the negative impacts of waste disposal.

One such agricultural waste material that has attracted attention for its potential in road stabilization applications is spear grass ash. Spear grass (*Cyperus rotundus*) is a widespread weed species found in many regions globally, often considered a nuisance in agricultural and natural ecosystems due to its aggressive growth and competitive nature. However, recent studies have explored the feasibility of converting spear grass biomass into ash through controlled combustion processes, with the aim of harnessing its inherent properties for engineering applications, including road construction and stabilization (Ahmad and Zaman, 2018).

The utilization of spear grass ash as a stabilizing agent in road subbase construction presents an opportunity to address multiple challenges simultaneously, including the management of agricultural waste, the enhancement of road infrastructure performance, and the promotion of sustainable development practices. By evaluating the engineering properties of subbase materials treated with spear grass ash, this research seeks to assess its effectiveness in improving stability, strength, and durability, thereby contributing to the advancement of sustainable infrastructure solutions.

Through experimental investigation and analysis, this study aims to provide valuable insights into the feasibility and practicality of incorporating spear grass ash into road construction practices. By examining the mechanical behaviour, moisture susceptibility, and other relevant properties of treated subbase materials, the potential benefits and limitations of spear grass ash as a sustainable stabilizing agent will be elucidated, informing decision-making processes in infrastructure planning, design, and implementation (Ali and Nyugen, 2022). The utilization of spear grass ash holds promise as a sustainable solution for road subbase stabilization, offering environmental, economic, and social benefits. By leveraging the abundant resources of agricultural waste materials and embracing innovative approaches to infrastructure development, we can strive towards a more resilient, efficient, and environmentally conscious transportation network (UNEP, 2011).

Objectives of the Study

This research objective is to systematically investigate the potential of spear grass ash as a stabilizing agent for road subbase materials. The specific objectives include:

a. To prepare the spear grass ash
b. To assess the physical and chemical properties of spear grass ash.
c. Evaluating the impact of spear grass ash on the mechanical properties of road subbase materials.
d. Comparing the performance of spear grass ash with traditional stabilizing agents.

MATERIALS AND METHODS

Materials

The materials used in this research work are as follows:

a. Subbase samples will be obtained from a borrow pit located along a road of Ulakwo Naze Owerri North LGA Imo State
b. The Spear grass ash used in the study for stabilization will be obtained locally from a groundnut post-harvest farm.

Methods

Chemical stabilization was carried out by addition of Spear grass ash to the natural soil samples at proportions of 2%, 4%, 6%, 8% and 10% by weight of the natural soil sample. Various test was performed during this project on the subbase material and they include;

a) Sieve analysis test: As stipulated in **BS 1377-2:1990** - Methods of test for soils for civil engineering purposes – Part 2: Classification tests.
b) Liquid limit and plastic limit test: As stipulated in **BS 1377-2:1990** – Methods of test for soils for civil engineering purposes – Part 2: Classification tests

c) Compaction test: As stipulated in **BS 1377-4:1990** – Methods of test for soils for civil engineering purposes – Part 4: Compaction-related tests
d) CBR test: As stipulated in **BS 1377-4:1990** – Methods of test for soils for civil engineering purposes – Part 4: Compaction-related tests

Calculations/Materials proportioning by Weight

Using a cylindrical mould of 152mm diameter x 178mm height

$$\text{volume of sample} = \frac{\pi D^2}{4} H = \frac{\pi (152)^2}{4} * 178 = 3229959.37 mm^3 = 0.00323 m^3$$

Take density = 1637kg/m^3

Density = $\frac{\text{Mass}}{\text{Volume}}$

Therefore, Mass = Density x Volume
Mass = 0.00323 x 1637 = 5.3kg

Including a 10% waste, the weight of a mould would be 5.3 X 1.1 = 5.83kg
Take weight = 6kg

Based on the mass, the different sample proportion can be obtained in Table 1

Table 1. Sample Proportion by Mass

Mix no	% Replacement	Subbase	Spear Grass Ash
SBB	0	6	0
SBB - C_2	2	5.58	0.12
SBB - C_4	4	5.16	0.24
SBB - C_6	6	4.74	0.36
SBB - C_8	8	4.32	0.48
SBB - C_{10}	10	3.90	0.6

RESULTS AND DISCUSSION

Results

The following results were obtained after the successful completion of the laboratory practical on the materials

a. Sieve Analysis Results

The results of sieve analysis test for the subbase material are presented in Tables 2 while the gradation chart for the subbase material is shown in Figure 1.

Table 2. Grain size distribution of subbase material

Sieve Size (mm)	Mass Of Soil Passing (g)	Percentage Of Soil Passing (%)
2.36	127	85
1.18	150	67
0.6	122	52
0.425	105	40
0.3	85	29
0.212	80	20
0.15	91	9
0.075	50	3
Pan	24	0

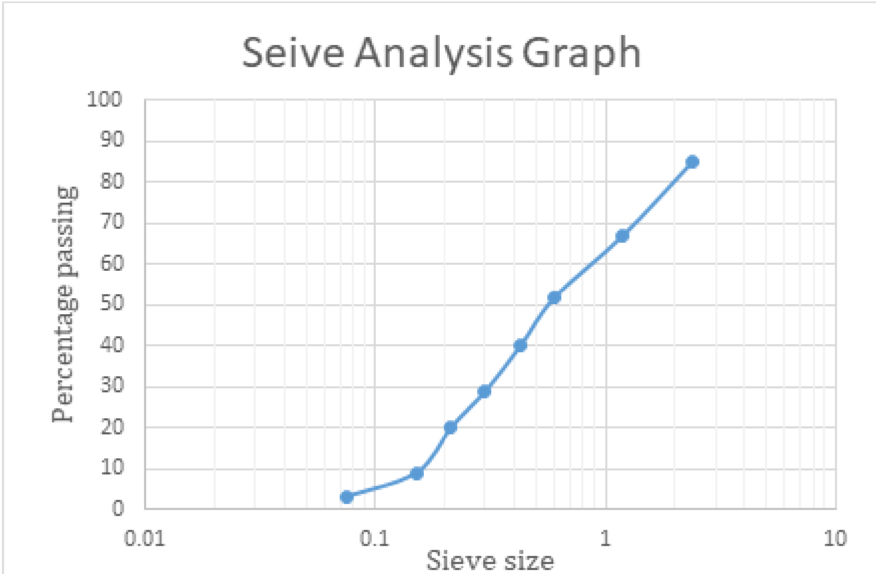

Figure 1. Particle Size Distribution Curve of The Subbase Material

Percentage passing sieve size 2mm = 80%
Percentage passing sieve size 0.425mm = 51%
Percentage passing sieve size 0.075mm = 4%

From the Figure 1, the values of D_{10}, D_{30}, and D_{60} for river sand are gotten and computed to get values for Coefficient of uniformity, (C_u) and Coefficient of gradation, (C_c) for the subbase material.
D_{10} = 0.17, D_{30} = 0.31, D_{60} = 0.85

$$\text{Coefficient of uniformity, Cu} = \frac{D60}{D10} = \frac{0.85}{0.17} = 5$$

$$\text{Coefficient of gradation, Cc} = \frac{(D30)^2}{(D60 \times D10)} = \frac{(0.31)^2}{(0.85 \times 0.17)} = 0.67$$

b. Liquid Limit and Plastic Limit Test Result

The result of the liquid limit and plastic limit test are given in Table 3 and Figure 2

Table 3. Liquid Limit and Plastic Limit Test Result

Test conducted	**Liquid limit**				**Plastic limit**	
Container Number	1	2	3	4	1	2
Wt. of can, M_1 (g)	19	18	20	19	19	19.5
Wt. of wet soil + can, M_2 (g)	59	50	47	41	50	52
Wt. of dry soil + can, M_3 (g)	45	41	41	37	45	46
Wt. of dry soil, $M_4 = M_3 - M_1$ (g)	26	23	21	18	26	26.5
Wt. of moisture, $M_5 = M_2 - M_3$ (g)	14	9	6	4	5	6
No. of blows, N	18	22	25	27		
Water content, w $= \frac{M_5}{M_4} \times 100$ (%)	54	39	29	22	11	23

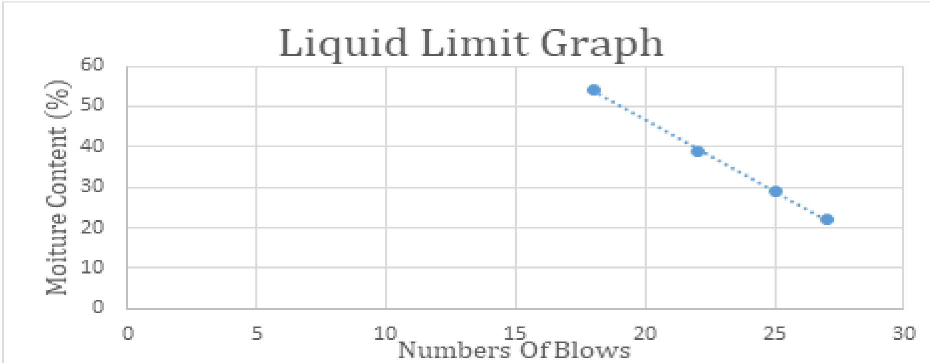

Figure 2. Liquid Limit Graph

Liquid Limit, LL $= 29\%$

Plastic index, PI $=$ LL – PL = 29- 20.9 = 8.1%

c. **Compaction and CBR Test Result**

For Compaction Test Results

The compaction test results are given in Table 4. Also, in Figure 3.

Table 4. Compaction Test Result for Subbase material (SB)

TEST NUMBER	1	2	3	4
MOISTURE CONTENT				
Mass of container, m_1 (g)	17	17	18	17.5
Mass of container $+$ wet soil, m_2 (g)	61	53	48	40
Mass of container $+$ dry soil, m_3 (g)	56	48.5	44	36.5
Mass of dry soil (g) $= m_3 - m_1$	39	31	26	19
Mass of water (g) $= m_2 - m_3$	5	4.5	4	3.5
Moisture content w (%) $= \frac{m_2 - m_3}{m_3 - m_1}$ x 100	12.8	14.5	15.38	18.42
DENSITY				
Mass of mould $+$ compacted soil, w_1 (g)	3150	3210	3150	3170
Mass of mould, w_2 (g)	1150	1035	1000	1200
Mass of compacted soil (g) $= w_1 - w_2$	2000	2175	2150	1970
Volume of compacted soil, v (cm^3)	1000	1000	1000	1000
Bulk density of soil (g/cm^3), $\rho_b = \frac{w_1 - w_2}{v}$	2	2.175	2.15	1.97
Dry density of soil (g/cm^3), $\rho_d = \frac{\rho_b}{1 + \frac{w}{100}}$	1.77	1.9	1.86	1.66

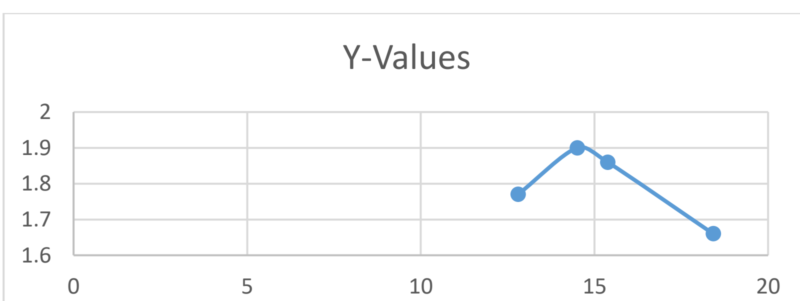

Figure 3. Compaction Curve

Maximum Dry Density = 1.9g/cm^3, Optimum Moisture Content = 14.5%

For California Bearing Ratio Test

Proving Ring Factor = 0.025, Standard load at 2.5mm = 13.7kN, Standard load at 5mm = 20.55KN

Table 5: CBR Test Result for Subbase material (SB)

Penetration (mm)	0.625	1.25	1.875	2.5	3.125	3.750	4.375	5.00	5.625	6.25
					SOAKED CBR TEST					
Dial Reading	17	26	32	40	44	48	50	55	57	58
Load (kN)	2.125	3.25	4	4.85	5.5	6	6.2	6.8	7	7.25
C.B.R (%)				35.4				33.09		
					UNSOAKED CBR TEST					
Dial Reading	28	47	76	90	103	114	120	130	135	140
Load (kN)	3.5	5.875	9.5	11.25	12.875	14.25	15	16.25	16.875	17.5
C.B.R (%)				82.1				79.08		

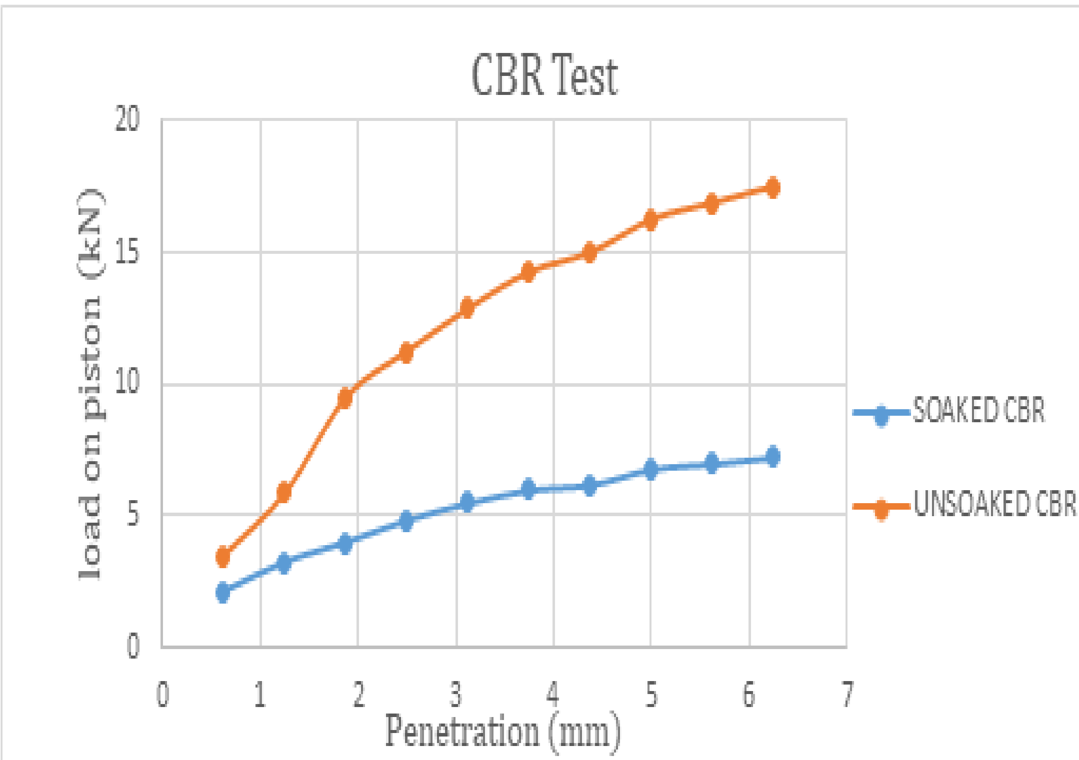

Figure 4. CBR curve

SOAKED CBR value = 35.4%
UNSOAKED CBR value = 82.1%

The summary of the compaction and CBR test result obtained for the different mixes are presented In Table 6, Figure 5, Figure 6, Figure 7 and Figure 8

Table 6. Compaction and CBR Test Result

Mix no	Maximum dry density (g/cm³)	Optimum moisture content (%)	Soaked CBR value (%)	Unsoaked CBR value (%)
SB	1.9	14.5	35.4	82.1
SGA-2	1.91	14	36.8	83.5
SGA -4	1.96	15	37.7	86.5
SGA -6	1.95	17	35.9	84.2
SGA -8	1.93	17	35.4	76.7
SGA -10	1.93	16.5	35.0	75.4

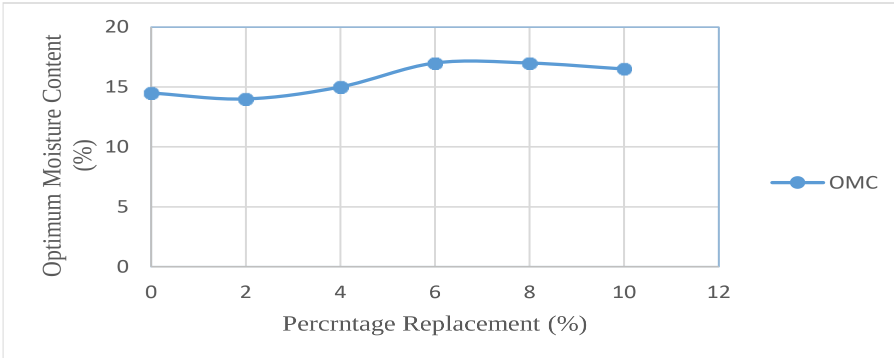

Figure 5. Optimum Moisture against Percentage Replacement

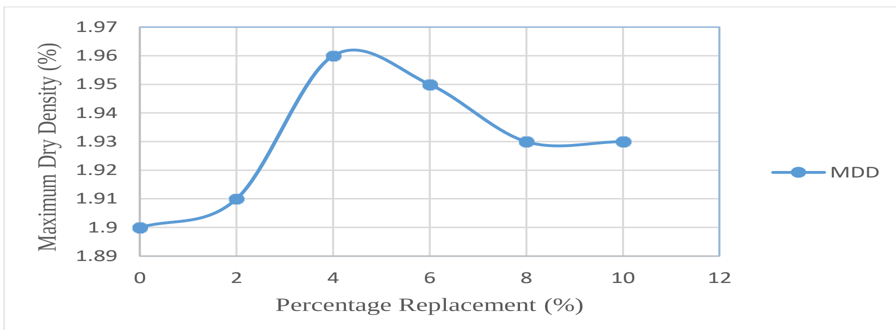

Figure 6. Maximum Dry Density against Percentage Replacement

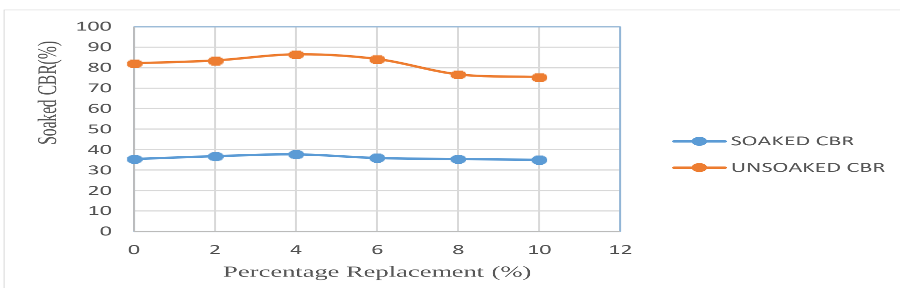

Figure 7. CBR against Percentage Replacement

Analysis of Results

a. Sieve Analysis and Particle Size Distribution

The sieve analysis test result shows an 80% passing at 2 mm, 51% passing at 0.425 mm, and 4% passing at 0.075 mm, this suggest a well-graded material, as there is a gradual reduction in particle size without abrupt drops. Cu = 5 indicates that the material has a good range of particle sizes, which is typical of well-graded soils. Cc = 0.67, which is below 1, suggests that although the soil is somewhat graded, it may not be perfectly ideal for structural stability without additional stabilization. This combination of Cu and Cc values suggests a moderately well-graded soil, making it suitable as a subbase material but possibly benefitting from added stabilizers to improve its load-bearing characteristics.

b. Atterberg Limits (Liquid Limit, Plastic Limit, and Plasticity Index)

These results suggest that the soil has low plasticity, making it relatively stable and less susceptible to volume changes with moisture fluctuations. This stability is beneficial for subbase applications, as the material will not swell or shrink significantly with changes in moisture content.

From the values presented in the sieve analysis and consistency limit test, the AASHTO classification of the subgrade material is classified A-2-4

c. Analysis of compaction and CBR Test

i. Maximum Dry Density (MDD)

The results show that the MDD of the subbase material slightly increases with the addition of spear grass ash (SGA) up to a certain point, after which it stabilizes. Specifically, the untreated subbase material (SB) has an MDD of 1.9 g/cm³. With a 2% SGA addition (SGA-2), the MDD increases marginally to 1.91 g/cm³, and it reaches its peak at 4% SGA (SGA-4) with an MDD of 1.96 g/cm³. For higher ash content (6% and beyond), the MDD shows a slight decrease or stabilization around 1.93–1.95 g/cm³. This trend suggests that adding up to 4% SGA helps improve the ease of compaction of the subbase material, possibly due to the fine particles filling voids in the soil structure and enhancing the density. Beyond this optimum level, the MDD stabilizes, likely due to excessive ash content disrupting the soil matrix rather than enhancing it.

ii. Optimum Moisture Content (OMC)

The OMC demonstrates a slight increase with higher SGA content. The OMC for untreated subbase material (SB) is 14.5%. With the addition of 2% and 4% SGA, the OMC slightly fluctuates around 14% to 15%. As the SGA content rises to 6% and above, OMC notably increases to 16.5% and 17%. This increase in OMC may be attributed to the increased surface area of the ash particles, which requires additional water for proper compaction. This trend implies that higher SGA percentages might demand more moisture to achieve optimal compaction, indicating that SGA impacts the water absorption and retention characteristics of the subbase material.

iii. California Bearing Ratio (CBR)

The CBR values, both soaked and unsoaked, reveal how SGA affects the strength characteristics of the subbase material:
Unsoaked CBR: The untreated subbase (SB) has an unsoaked CBR value of 82.1%. At 2% and 4% SGA, there’s a slight improvement, with CBR values reaching 83.5% and 86.5%, respectively, suggesting improved stability. With SGA contents of 6% and above, the unsoaked CBR values begin to decline slightly, with SGA-10 showing a CBR of 75.4%.
Soaked CBR: The untreated sample (SB) has a soaked CBR of 35.4%. With SGA addition at 2% and 4%, there is a slight increase in soaked CBR, reaching 36.8% and 37.7%. However, the soaked CBR values decrease when the SGA content reaches 6% and higher, eventually dropping to 35.0% for SGA-10.

Generally, these results indicate that 4% SGA appears to be the optimal content, yielding the highest improvement in both unsoaked and soaked CBR values. Beyond this point, the additional ash might create a weaker bond due to excess fines, which compromises strength. This is evident in the declining CBR values at higher SGA percentages, both in soaked and unsoaked conditions.

CONCLUSION

After the successful completion of this project, the following conclusions are made:

a. The optimal results in maximum dry density (MDD) and optimum moisture content (OMC) were observed at 4% SGA (MDD of 1.96 g/cm³ and OMC of 15%). Beyond 6% SGA, there was a decline in both density and unsoaked CBR values, suggesting an ideal SGA content for optimal compaction is around 4-6%. This concentration allows the subbase material to achieve its highest density and strength.

b. Both soaked and unsoaked CBR values indicate improved performance with the addition of SGA. Unsoaked CBR reached a peak of 86.5% at 4% SGA, indicating excellent load-bearing capacity. However, beyond 4%, there was a decline, especially in unsoaked CBR values, suggesting that higher SGA content may reduce structural integrity due to possible agglomeration or reduction in ease of compaction. The soaked CBR values, although lower than unsoaked, remained satisfactory, showing that SGA-stabilized subbase material maintains adequate strength even in wet conditions.

c. SGA as a stabilizing agent demonstrates improvements in mechanical properties, particularly up to an optimal range (4-6%). At this range, SGA provides enhancements in compaction density and CBR values, indicating its suitability as an eco-friendly alternative stabilizer for road subbase applications.

Recommendations

a. Based on the findings, a spear grass ash content of 4-6% is recommended for stabilizing road subbase materials. This range provides the best balance of density, moisture content, and load-bearing capacity as observed in the compaction and CBR test results.

b. Field testing and monitoring of roads constructed with SGA-stabilized subbase materials would provide valuable data on the practical performance and any necessary adjustments to the mix design based on real-world conditions.

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